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B. Petrie, D.J.W. Piper, M. Willison
Editor: James E. Stewart
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Volume 42, Part 1, pp. 1-8.

THE OCEANOGRAPHY OF THE BRAS D'OR LAKES: GENERAL INTRODUCTION[1]

In March, 1996 the Cape Breton First Nation communities organized a workshop focussing on the Bras d'Or Lakes watershed to discuss the ecological research and monitoring and to develop a strategy to initiate projects arising out of the meeting. Six of the authors in this volume participated in this workshop. Subsequently, a number of general meetings have been held in Cape Breton; smaller groups, discussing the oceanography, have met at Bedford Institute. These meetings led to the 1999 Bras d'Or Lakes Ecosystem Workshop that set out 11 recommendations that identified priority items for scientific research (Lambert, 1999). In addition to the science issues that arose, the local involvement in these meetings, the interest shown, and the effort the community extended to understand the oceanography have been impressive. This positive feedback, along with current scientific activity, motivated us to propose an issue of the Proceedings of the Nova Scotian Institute of Science (NSIS) devoted to the oceanography of the Bras d'Or Lakes (Fig 1). Our goals are to provide a review of current knowledge of the oceanography of the Lakes and to present new data and

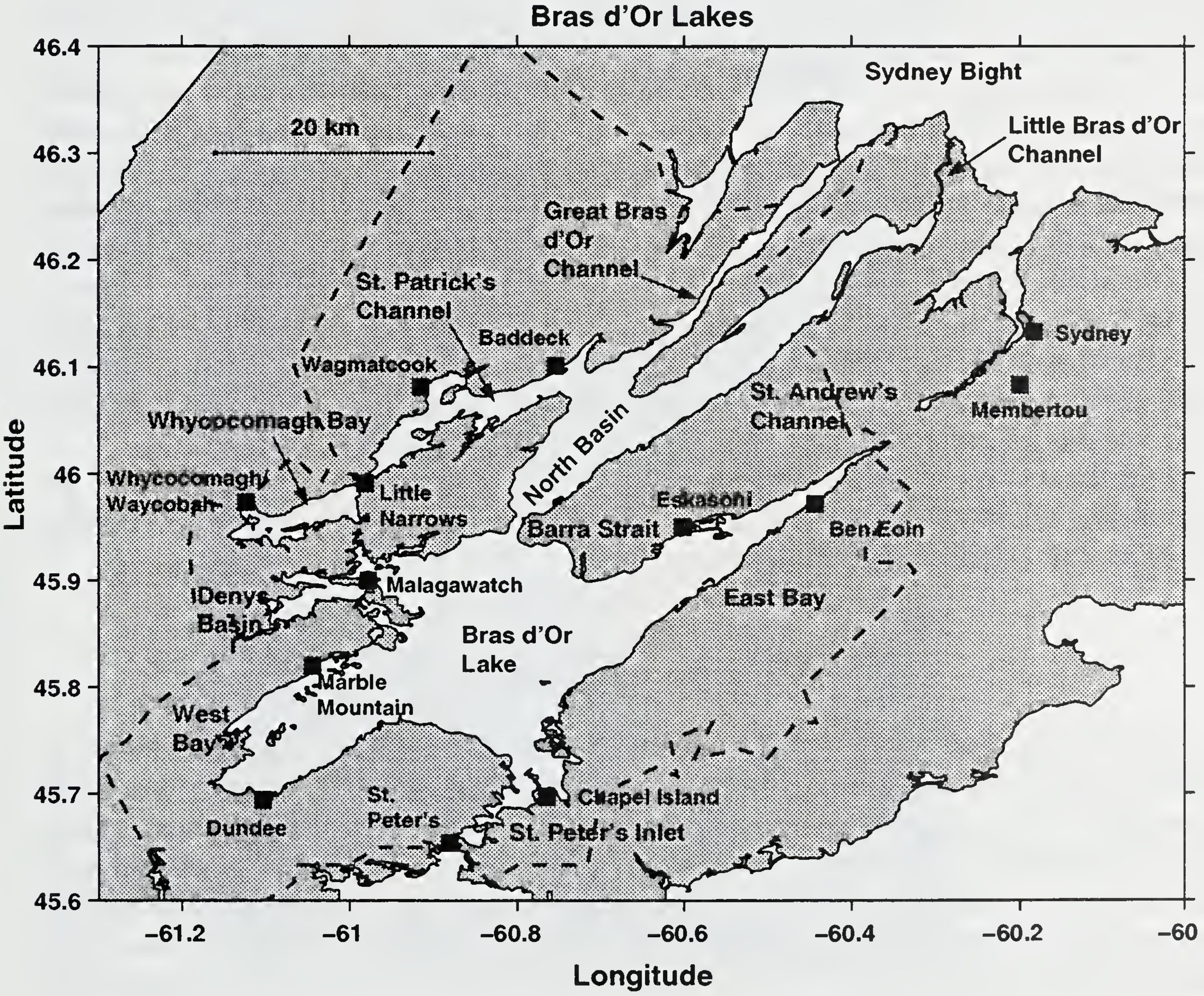

Fig 1 Map of the Bras d'Or Lakes indicating place names used in the text and the statistical area (broken line) of the 1996 Statistics Canada survey.

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[1] Prepared by Brian Petrie, Ocean Sciences Division, Bedford Institute of Oceanography, Dept. of Fisheries and Oceans, Dartmouth, Nova Scotia

analyses to a broader community interested in the Lakes but one that may not have an extensive oceanographic background. This review builds on a conference focussed on aquaculture held in Sydney in 1975 (McKay, 1975).

A question that frequently arises is whether the Lakes are brackish water lakes or an inland sea. In their classic book on oceanography, Sverdrup, Johnson and Flemming (1942) tabulate the surface areas and volumes of the marginal (at the edges of the oceans) and mediterranean (inland) seas. The seas had 70 to 2100 times greater surface area than the Bras d'Or Lakes, and 125 to 100,000 times the water volume. Given their present area, the Lakes would require an average depth of 3700 m to equal the volume of the smallest sea in the tabulation. Given their average depth of about 30 m, the Lakes would have to have a surface area equal to 60% of the surface area of the Gulf of St. Lawrence to equal the volume of the smallest sea. If we choose to call the Lakes an inland sea, then clearly it would be a very small one. On the other hand, Pickard (1979) defines an estuary as "a semi-enclosed coastal body of water having a free connection to the open ocean and within which sea-water is measurably diluted with fresh water deriving from land drainage". This definition is very broad, but as it captures the essence of the water properties of the Lakes, I conclude that the most suitable descriptive term for them is "estuary".

Two things in particular surprised me while acting as guest editor of this volume. I had thought that the deep areas of St. Andrew's Channel (to 280 m) were caused by scouring during the advance and retreat of glaciers. Shaw *et al.* (2002), however, report that the deep areas may have been salt outcrops that dissolved when they contacted ground water. The second surprise comes from their re-creation of the shoreline of the Lakes (their Fig 12 and 13) when sea level was 25 m lower than at present, about 6000 to 9500 years ago (Fig 2A, B). St. Patrick's Channel was a river with small lakes where Whycocomagh Bay is now. Denys Basin and the northwestern portion of Bras d'Or Lake were dry land. East Bay was a lake joined to a much smaller bay. The only connection to the ocean was through the Little Bras d'Or Channel. They believe that the Little Bras d'Or Channel is filled with sediment now, making it the secondary connection to the ocean relative to Great Bras d'Or Channel. The water properties of the Lakes would certainly have been quite different from what they are now.

As the Lakes are a fundamental part of the environment for the people in the surrounding countryside, a brief overview of social aspects of the region is included as part of an extended introduction.

The Regional Context[2]

Inland bodies of water have an influence on, and are influenced by, the activities of people around them. Consequently, any study of the Bras d'Or Lakes would be incomplete without reference to the socioeconomic features of the surrounding area (Fig 1). The difficulty, however, is a lack of available data. Most data collection has been done by municipal or county groupings and data have not been compiled in a way that would indicate the cumulative interaction of people with the ecosystem of the Lakes. While it is self evident that the impacts of this interaction would be substantial, they have yet to be studied.

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[2] Prepared by Janice Raymond, Policy and Economics Branch, Maritimes Region, Department of Fisheries and Oceans, Marine House, Dartmouth, Nova Scotia.

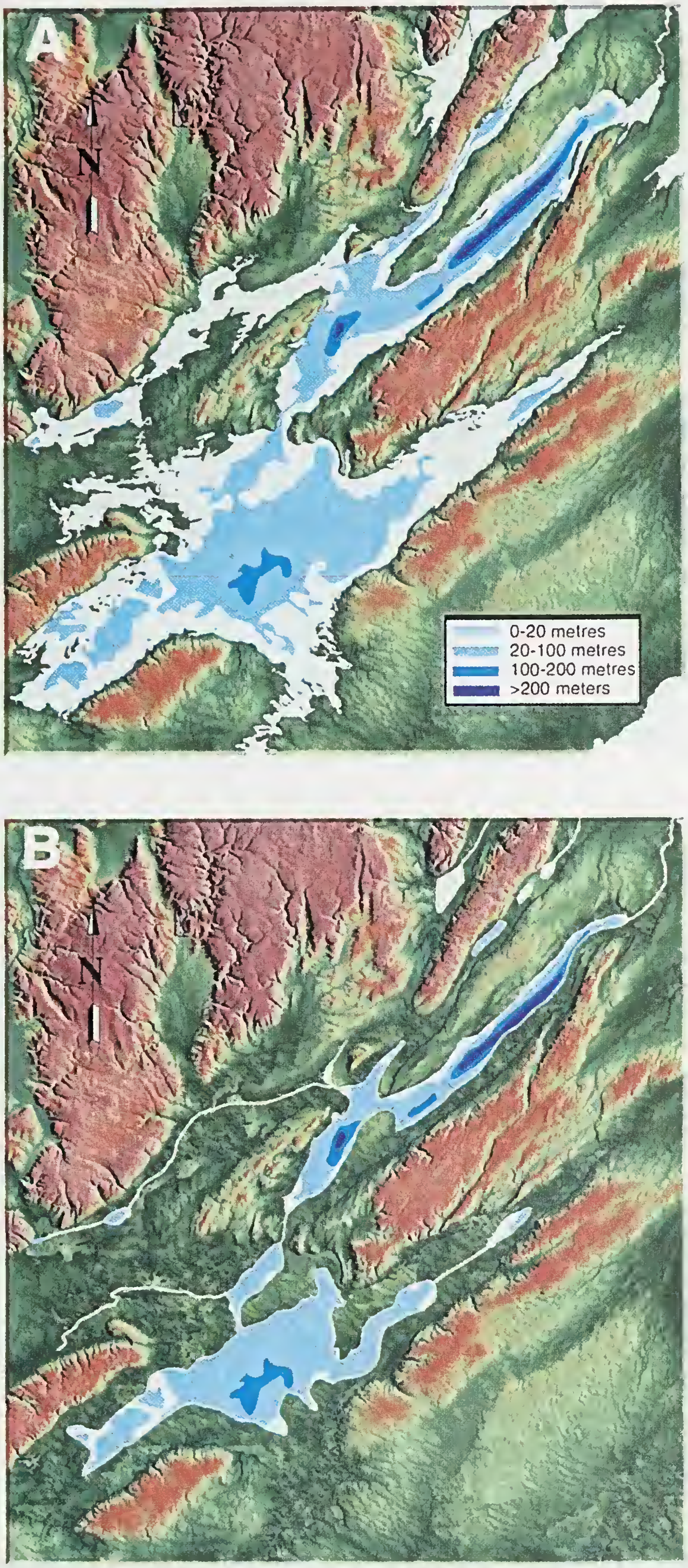

Fig 2 (**A**) Present shoreline of the Bras d'Or Lakes. (**B**) Shoreline 9500-6000 years before present (Shaw *et al.*, 2002). For the land, dark green shading represents elevations less than 30 m above sea level, light green shades represent 30-150 m above sea level, and brown represents land >150 m above sea level.

Based on the Census of Canada, 1996, the population of the enumeration areas touching the shoreline of the Lakes was 13,725 (Fig 1). Most of the communities are small and unincorporated. With the exception of Eskasoni, individual community populations do not exceed 1,000 (Statistics Canada, 2001).

The region adjacent to the Bras d'Or Lakes is rural in character with a natural landscape that makes it an attractive recreational area. Commercial fishing and aquaculture industries are based on the resources of the Lakes and contribute to the regional economy. Recreational activities, particularly fishing and boating, are sources of income as well as enjoyment for inhabitants and tourists. On an industry basis, the services sector is the largest employer in the Lakes region (Fig 3). Unemployment, however, is an ongoing problem amounting to 27.8% of the workforce in the 1996 census and is a factor driving many of the local efforts aimed at economic improvement. The community of Baddeck (population 937), on the northern side of the Lakes, is located on a tourist route through the Island to Cape Breton Highlands National Park and the Cabot Trail. Baddeck is a popular recreational area, highlighted by a Historic Park commemorating Alexander Graham Bell.

On the northern side of the Island, the Great Bras d' Or Channel is one of the major connections between the Lakes and the ocean. Shipments of gypsum mined at Little Narrows pass through here. At St. Peter's, on the southern side, a man-made canal connects the Lakes to the ocean. Marble Mountain, as the name implies, was once a

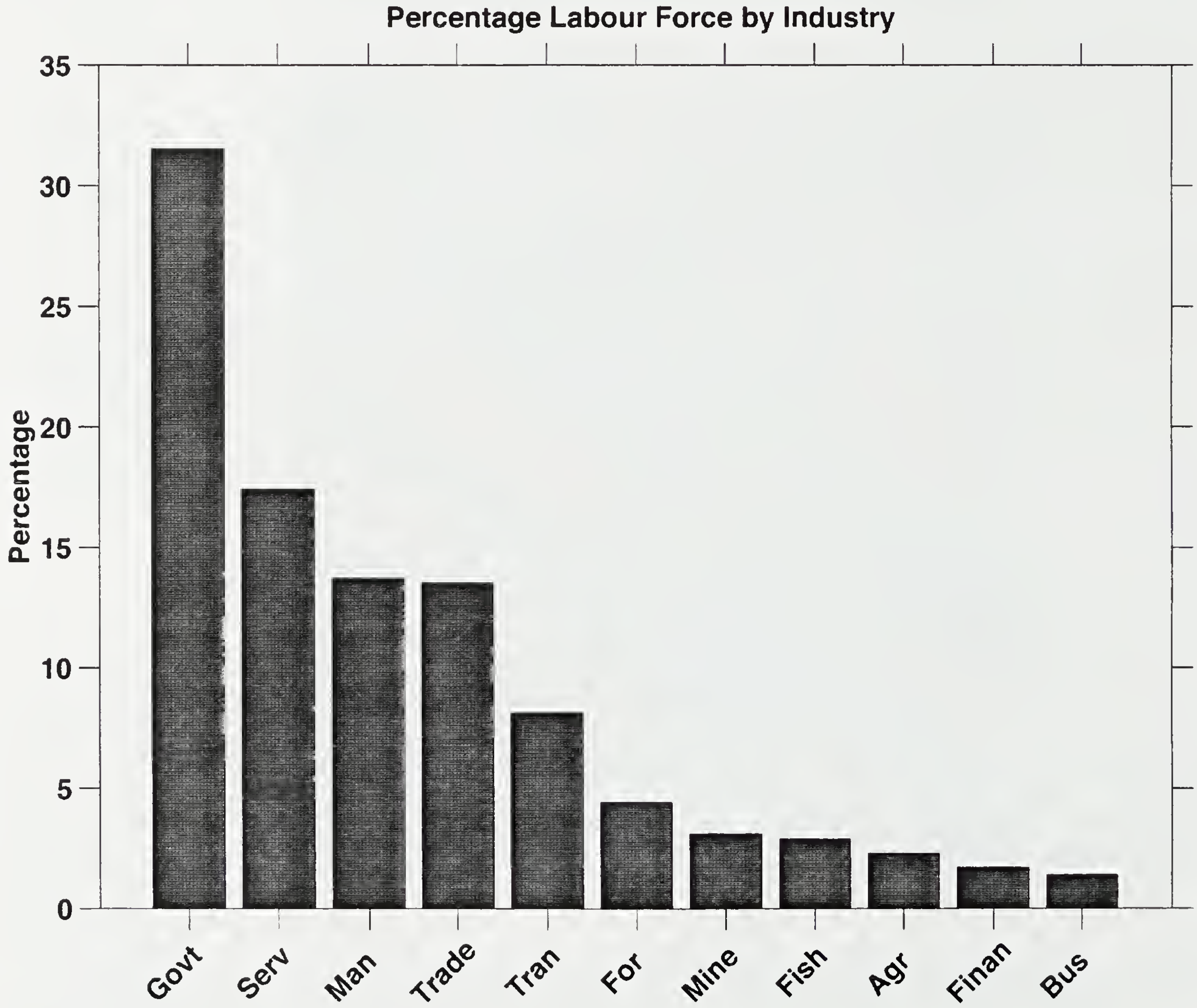

Fig 3 Percentage labour force by industry based on the 1996 Statistics Canada survey.

marble quarry. The heritage of the Mi'kmaq[3] and early Scottish settlers is reflected in names like Whycocomagh and Eskasoni, or Ben Eoin and Dundee, respectively.

Aboriginal identity is strong in the Lakes region where five Mi'kmaw communities are located (Fig 1). The 1996 census (Statistics Canada 2002) indicated that the largest First Nation community was Eskasoni (2,504), followed by Whycocomagh/Waycobah (574), Wagmatcook (448), and Chapel Island (350). The fifth community of Membertou (612), while not situated on the shoreline also has a significant tie to the Lakes. One direct example of that link is through Malagawatch, which is reserve land that was set aside in 1958 for joint use by each of the five communities (Howe, 2002). The Mi'kmaw language is spoken by ~3,400 people in the Bras d'Or Lakes area.

The distribution of the population by age group (Fig 4) is similar to the Cape Breton and provincial profiles in most respects. The percentage of the population under 25 is 6.3% higher for the Bras d'Or Lakes region than for the province as a whole.

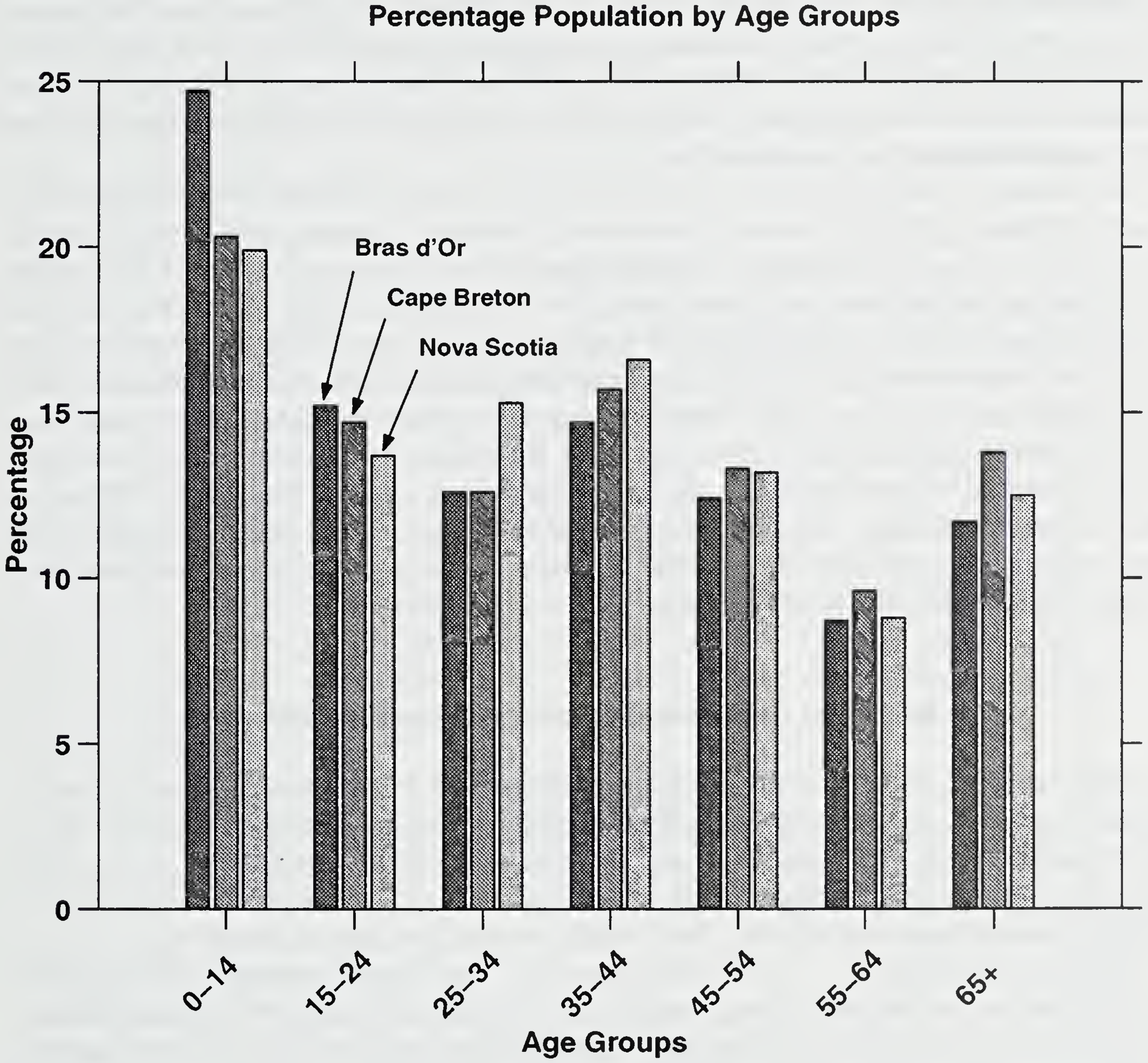

Fig 4 Percentage distribution of population by age group for the Bras d'Or Lakes (dark grey bar), Cape Breton Island (medium grey) and Nova Scotia (light grey) based on the 1996 Statistics Canada survey.

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[3] Use of the terms Mi'kmaq and Mi'kmaw conforms to that described in the *Mi'kmaw Resource Guide (1997)* whereby " Mi'kmaw" is the singular of "Mi'kmaq". "Mi'kmaw" is also used as an adjective where it precedes a noun such as Mi'kmaw people, Mi'kmaw person etc.

Although the census provides a convenient method of defining the area, there is bound to be some distortion because parts of the enumeration areas covered are quite removed from the Lakes. The watershed may be more appropriate since the rivers in that area flow into the Lakes and disturbances initiated there could have serious impacts. It is more relevant to refer to the watershed on issues relating to the sustainable management of the ecosystem. Methodology is needed to enable estimates to be made of socioeconomic aspects extrapolated from data already collected on the basis of other categories or groupings.

An examination of the commercial and recreational uses of the Lakes and the potential conflicts among uses are important areas for study. A comparative study, perhaps with other similar lake regions, would be useful in determining what social demographic characteristics would advance an understanding of the region. For example, a sociological study might focus on determining the implications of such factors as population density, education or income distributions to provide more understanding of the relationships between the people living in the area of the Lakes and the impacts of the Lakes' resources. An economic assessment of the value of the Lakes would help to clarify their importance and emphasize the point that, as well as aesthetic values, there are economic incentives to protect the Lakes from contamination or other destructive exploitation.

An economic assessment is currently being proposed by the Bras d'Or Stewardship Society (Bates, 2002). The Society, which has a Board of Directors and a membership of about 200, was incorporated under the Nova Scotia Societies Act in 1997. While work is done primarily on a volunteer basis, the Society organizes specific projects that are cost-shared with various levels of government. The main effort is towards the reduction and elimination of the discharge of untreated sewage into the Lakes. It works with other organizations, particularly neighbouring First Nations communities, to promote the protection and conservation of the Lakes. The proposal to assess the contribution of the economy of the watershed area covers the shellfish fishery, aquaculture, the tourism industry, commercial shipping industry and the recreational sector. This study would be an important step in increasing awareness and understanding of the regional context of the Lakes.

Direction of Future Oceanographic Studies[4]

There has been considerable oceanographic research in the Bras d'Or Lakes for the past several years and it is anticipated that work will continue into the near future. This volume presents results from these and reviews of earlier related studies. It has also given the opportunity to consider the next steps future studies could take that would build on current and past efforts. These steps are outlined below by discipline.

Physical oceanography. The development of a fine scale circulation model of the Lakes driven by freshwater inflow, wind, tides and external forcing from Sydney Bight is an attainable goal. The oceanographic database essential to evaluate the model's performance is sizable and growing. Moreover, the nearly fully enclosed nature of the Lakes makes boundary conditions easier to handle than for the open ocean. The model should be able to incorporate natural and human-derived inputs and thereby contribute to water quality issues in the Lakes, identified by the 1999 Bras d'Or Lakes Ecosystem Workshop as the "overriding problem in the Bras d'Or Lakes". A project (fall 2000 to fall 2002) in St. Andrew's Channel and Bras d'Or Lake will address the overall heat budget and the role of wintertime convection in deep water renewal in the Lakes. However, observations of ice thickness are not being made and are an important element of these problems.

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[4] Prepared by Brian Petrie from submissions provided by authors of individual articles

Chemical oceanography. Research over the last several decades has provided sufficient information to understand the distribution of dissolved oxygen, the sources and distributions of nutrients, and some aspects of the role of nutrient supply in the biological productivity of the Lakes ecosystem. The almost complete lack of winter data means that two important processes in the nutrient and oxygen cycles are not well understood. The first is the increase in nutrient levels in the surface layer through the winter that provides most of the nutrients that fuel the spring bloom. Understanding the productive capacity of the Lakes will require nutrient observations in late winter and direct measurements of the bloom. The second process is the renewal of deep waters in the major basins. The dissolved oxygen data clearly indicate that even the deepest waters in St. Andrew's Channel are periodically renewed, but the mechanisms and frequency of this renewal are not known. Comparing oxygen data from the 1990s with the limited data from the 1970s suggests that there may be long term variations in deep water properties consistent with irregular replacement of these deep waters. Recent winter measurements of physical properties of deep water coupled with wintertime measurements of nutrients and oxygen will help to improve the understanding of deep water renewal.

Invertebrate community. Fundamental questions remain regarding the community of epibenthic invertebrates in the Lakes including the species composition and the factors that determine it. The benthic invertebrates are of interest not only because they include commercial species, but because of their ecological roles in recycling detritus and as a food source for other species including groundfish. Future research should include studies of spatial and seasonal changes in species composition in relation to the physical environment. Habitat maps, e.g. from multibeam bathymetry, will aid planning benthic surveys and significantly advance our understanding of animal-habitat linkages. Studies of the population biology of lobsters, crabs and oysters are of interest because these species are important components of the ecosystem, economically valuable, and serve as models for species with similar life histories. To understand why, for example, lobster landings are lower in the Lakes compared with the open Cape Breton coast, studies are needed of lobster distribution, movement, condition and production in both areas. Such studies should cover the full range of the life history of the lobster.

Plankton and fish. Our knowledge of the fish in the Lakes is quite extensive and that of the zooplankton improving rapidly. A zooplankton survey is underway and samples are being analysed; however, counting and identifying planktonic species is a slow process; considerable time will elapse before these studies are completed. Knowledge of the phytoplankton community is minimal but will improve as the results from studies underway and planned are realized.

Marine geology. Future work on the glacial and early post-glacial history of the Lakes will require piston coring or drilling from a ship or winter ice platform into older sediments and subsequent radiocarbon dating. Correlations must be established with the long boreholes in clay recently acquired by the Nova Scotia Dept. of Natural Resources in the areas to the west of the Bras d'Or Lakes. Additional high-resolution seismic reflection profiles are needed to identify features revealed by multibeam bathymetry. Furthermore, it is vital that backscatter data, indicative of sea-floor reflectivity, be integrated with multibeam imagery and ground-truth information to enhance our understanding of bottom materials. The Geological Survey of Canada is developing standards for interpretive maps (including a habitat map) based on multibeam bathymetry. It is hoped that maps of the Bras d'Or Lakes will be among the first to be produced using this new system.

Shore dynamics and evolution. We have observed that the depositional shore features in the Bras d'Or Lakes evolve through a cycle of growth, stabilization, breakdown and collapse. Field surveys of the physical characteristics and determination of the age of existing barriers are required to confirm the model of coastal barrier evolution. The impacts of sea ice on the growth and stability of coastal barriers requires further investigation. New multibeam bathymetric images collected by the Canadian Hydrographic Service show spectacular examples of similar depositional features preserved underwater throughout the Lakes. These submerged shore features provide information for mapping the paleo-shorelines and their elevation relative to present sea level. They will help to map the existence of individual lakes in the basin and when they became linked to each other. The paleo-shoreline maps can be used to select the best sediment coring locations where datable material may occur leading to a more accurate analysis of sea level history and shoreline evolution of the Lakes. This information has great significance for researchers looking for archaeological sites or physical features such as old river channels.

Acknowledgements

We thank Dr. James E. Stewart, editor of the Proceedings, for his encouragement throughout the production of this volume and for his editorial assistance. We thank the external reviewers for their constructive criticism of the science and for their suggestions of how to make the science more accessible to the general public.

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THE PHYSICAL OCEANOGRAPHY OF THE BRAS D'OR LAKES

BRIAN PETRIE[1] and GARY BUGDEN
Ocean Sciences Division
Department of Fisheries and Oceans
Bedford Institute of Oceanography
P. O. Box 1006, Dartmouth, N. S. , Canada B2Y 4A2

In the Bras d'Or Lakes the mean water circulation for the spring to fall seasons consists of a surface flow towards the ocean and a subsurface flow into the Lakes. The outflow from the Lakes is about 1100 $m^3 s^{-1}$. Vertical exchanges and flushing times throughout the Lakes and their effects on oxygen distribution are discussed. Currents at some locations in the Lakes are frequently so weak that they cannot turn the rotors of conventional current meters; at other sites, they can be so strong that they rival flows in the Bay of Fundy. Of note are observations from Barra Strait and the Great Bras d'Or Channel that feature maximum flows of about 1 and 3 $m s^{-1}$, dominated by strong semi-diurnal tidal currents. Temperature and salinity change markedly from Sydney Bight into the Lakes and vertically within the Lakes. Sea level variations caused by tides decrease rapidly from the entrance to the Lakes along the Great Bras d'Or Channel. On the other hand, low frequency fluctuations are only slightly attenuated. Surface wave data from the North Basin and Bras d'Or Lake compare reasonably well with equations that relate wind speed and fetch to significant wave height. The long-term mean ice cover for the Lakes is derived from 30 years of data. Below (above) normal winter air temperatures are related to above (below) normal ice cover.

Dans les lacs Bras d'Or, la circulation moyenne de l'eau du printemps à l'automne consiste en un écoulement de surface en direction de l'océan et un écoulement en profondeur vers l'intérieur des lacs. Le débit sortant du lac est d'environ 1 100 $m^3 s^{-1}$. On discute ici des échanges verticaux et du temps de renouvellement des eaux du lac, ainsi que de leurs effets sur la distribution d'oxygène. En certains endroits du lac, les courants sont souvent si faibles qu'ils n'actionnent pas les rotors des courantomètres; en d'autres endroits, ils peuvent être si forts qu'ils rivalisent avec ceux de la baie de Fundy. À noter que des observations en provenance du détroit de Barra et du chenal Great Bras d'Or indiquent des courants maximaux d'environ 1 et 3 $m s^{-1}$, dominés par de forts courants de marée semi-diurne. La température et la salinité changent nettement entre la baie de Sydney et les lacs, ainsi que verticalement au sein de ces derniers. Les variations du niveau de la mer dues aux marées diminuent rapidement à partir de l'entrée des lacs le long du chenal Great Bras d'Or, mais les fluctuations de basse fréquence sont quant à elles à peine atténuées. Les données de vagues dans le bassin North et les lacs Bras d'Or montrent une comparaison assez bonne avec la relation théorique entre la vitesse du vent, la portée du vent et la hauteur significative des vagues. La couverture de glace moyenne à long terme est calculée à partir de trente ans de données. Les températures hivernales de l'air inférieures (supérieures) à la normale sont associées à une couverture de glace supérieure (inférieure) à la normale.

Introduction

The Bras d'Or Lakes are connected to Sydney Bight and the Atlantic Ocean by a 30 km long, narrow, shallow passage, the Great Bras d'Or Channel (Fig 1). The channel has an average width of about 1.3 km, an average depth of about 19.5 m and a maximum depth of 95 m. The most severe restriction is at the mouth of the channel where it opens onto Sydney Bight. There the width is only 320 m, the maximum depth is 16.2 m, and the cross-sectional area is 2400 m^2. It is through this small opening that most of the water exchange between the Lakes and the ocean must occur.

The 8 km long Little Bras d'Or Channel, the only other permanently open connection to the ocean, is even more restrictive. It is less than 100 m wide and 5 m deep on average. It does not appear to play a major role in the temperature and salinity

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[1] Author to whom correspondence should be addressed

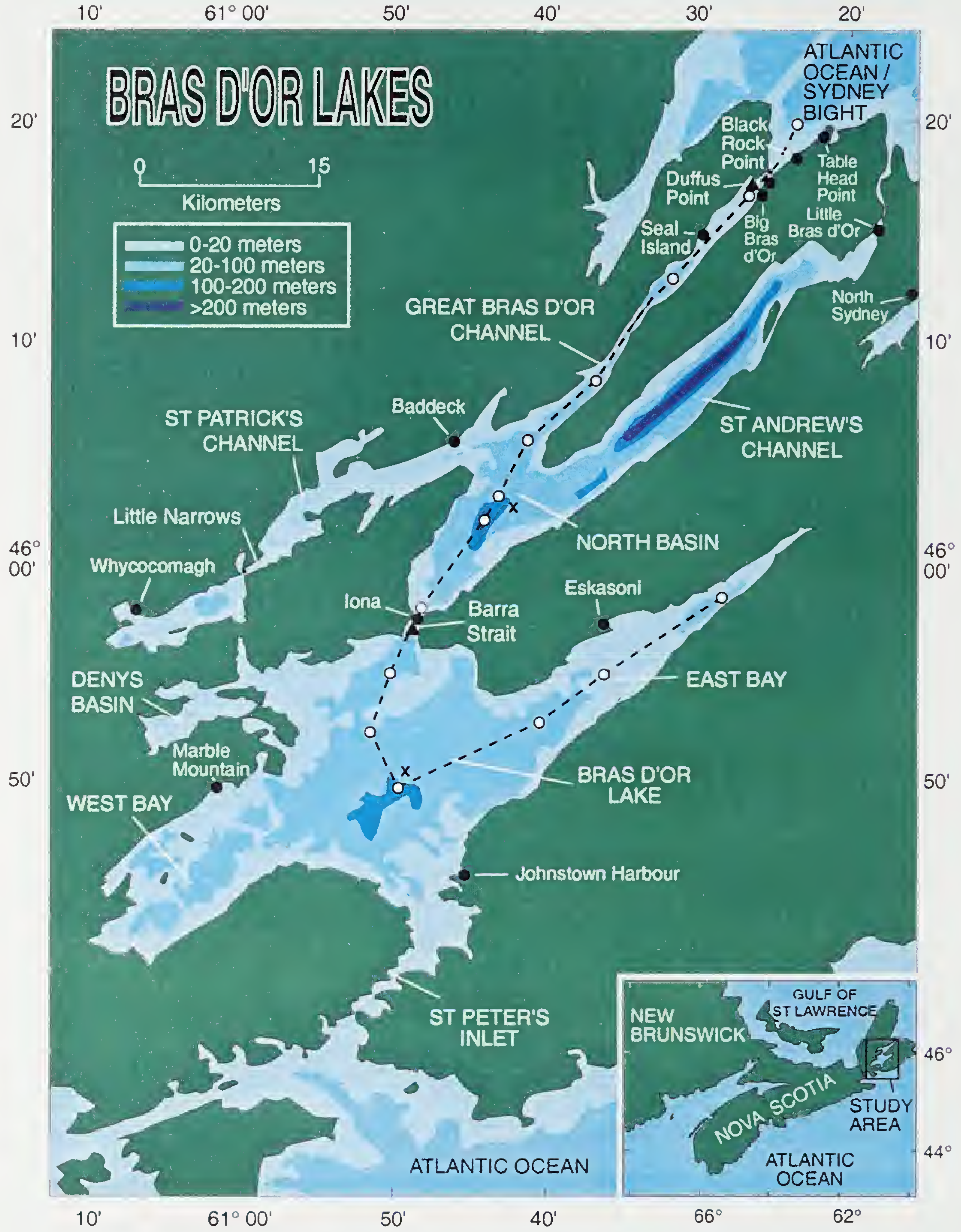

Fig 1 Map of the Bras d'Or Lakes with place names used in the text. Sites of tide gauges (solid dot), moorings measuring current, temperature and salinity (solid triangle), wave rider buoys (x) and ship-based temperature and salinity stations (open dot, dashed line) are shown.

distributions in the Lakes (Gurbutt and Petrie, 1995). A lock on St. Peter's Inlet on the southern side of Bras d'Or Lake is opened occasionally to allow vessels to enter or leave the Lakes. Before the St. Peter's Canal was completed in 1869 after 15 years of digging, blasting and drilling, ships were hauled across the isthmus to the Lakes on skids. The major obstacle encountered during the construction was a solid granite hill 20 m high (Parks Canada, 2001).

The interior of the Lakes consists of several interconnected basins and channels with a maximum depth of 280 m in St. Andrew's Channel. Two passages of note are Barra Strait which controls the exchange between the North Basin and Bras d'Or Lake, and Little Narrows which separates Whycocomagh Bay from St. Patrick's Channel. The Lakes have a shoreline of about 1000 km excluding islands (from 1:50 000 digital charts), total surface area of about 1.07 billion m^2, and a volume of approximately 32 billion m^3.

The restricted exchange with the Atlantic Ocean, freshwater inflow, and the exchange of heat between the atmosphere and the water are major factors influencing the circulation, temperature and salinity of the Bras d'Or Lakes.

The physical oceanography of the Lakes involves the circulation, both the average currents and the fluctuating currents caused by tides, wind and freshwater inflow, the distribution of temperature, salinity and density, the variations of sea level, mixing within the Lakes, surface waves and ice cover. These processes also affect other variables including the distribution of nutrients and dissolved oxygen in the water, the movement of sediments, the dispersion of pollutants and consequently water quality, and coastal erosion. A knowledge and understanding of these physical processes are fundamental to responsible and effective management of the Lakes.

In the following sections, we present brief discussions of the mean circulation of the Lakes, mixing processes and upwelling, flushing times for the separate basins of the Lakes, the distribution of temperature and salinity, tidal and non-tidal currents and sea level changes, surface waves and ice cover.

Mean Circulation

The Bedford Institute of Oceanography conducted broad scale surveys of the Lakes from 1972 to 1974, making measurements of temperature, salinity, and dissolved oxygen concentrations from ships and small boats (Krauel 1975a, b). In addition, recording instruments were moored at depths ranging from 4 to 183 m below the surface in the spring and summer of 1973 and 1974. These current meters measured speed and direction of water flow at 13 locations throughout the Lakes; each record was about 1 month long. Seven sites were occupied only once, 4 sites twice, and 2 sites three times. Twenty eight records were collected in 1973, 21 in 1974. Sea level recorders were also placed at 9 shore locations at the same time.

These data were used by Gurbutt and Petrie (1995) to derive a picture of the mean water circulation in the Lakes for the spring, summer and fall seasons. There were too few data from the winter to extend the circulation into that season. Moreover, during the winter, the Lakes are frequently covered completely by ice, a condition that could profoundly affect the circulation by cutting off direct contact with atmospheric forcing. The circulation in the upper (0-10 m) and lower (10-50 m or bottom if less than 50 m) layers of the Lakes are shown schematically in Fig 2A, B. The thickness of the lines depicting the currents is proportional to the amount of water transported. The thicker the line the greater the quantity of water moving, and vice versa.

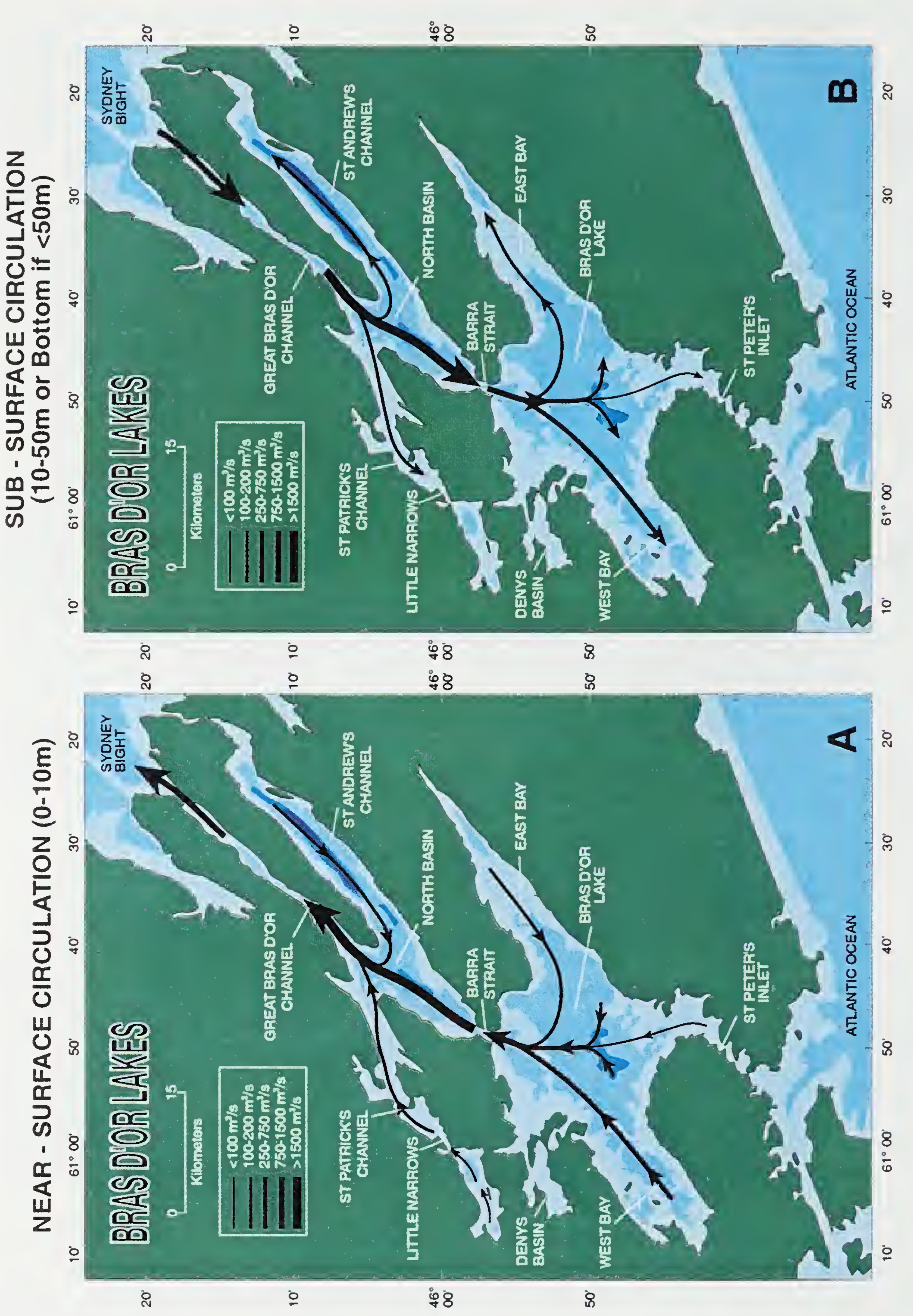

Fig 2A Map of the near-surface circulation in the Bras d'Or Lakes. The thickness of the line is proportional to the strength of the flow. **(B)** Map of the sub-surface (approximately 10-50 m) circulation in the Bras d'Or Lakes. The thickness of the line is proportional to the strength of the flow.

Beginning in the southwestern region of the Lakes, the surface layer flows from West and East Bays, the former about 3 times stronger than the latter, and joins the currents in Bras d'Or Lake to form a strong flow through Barra Strait into the North Basin. This flow then combines with weaker flows from St. Andrew's and St. Patrick's Channels to form a near-surface current through the Great Bras d'Or Channel that discharges into Sydney Bight (Fig 2A). The surface circulation carries the freshwater runoff from the Lakes into the ocean.

The sub-surface circulation is almost a carbon copy of the near-surface flow but in the opposite direction (Fig 2B). In the Great Bras d'Or Channel, the sub-surface current moves from Sydney Bight into the North Basin, St. Andrew's and St. Patrick's Channels. The current in North Basin flows through Barra Strait into Bras d'Or Lake and then into West and East Bays. The sub-surface flows carry relatively salty water from Sydney Bight into the Lakes.

The circulation shown in Fig 2A, B must conserve mass; i.e., for each layer in each area of the Lakes, the mass of water entering a layer must equal the mass of water leaving. The flows can be either horizontal, from one area to an adjacent area, or vertical, from one layer to another within the same region of the Lakes. Carried to an extreme, if mass conservation *did not* hold then, over time, the Lakes would either drain completely, if more water flowed out than in, or flood the adjacent countryside, if the opposite were true. Similar conservation principles hold for salt and heat. If the amount of salt in the Lakes remains constant, the quantity entering the system must balance the amount leaving. If the total salt content in the Lakes is increasing, more must come in then leave and vice versa. The water temperatures in the Lakes depend on balances between the sources or sinks of heat; e.g., in spring and summer there is a net transfer of heat from the atmosphere to the Lakes, in winter the opposite is true. The flow from Sydney Bight generally brings colder water into the Lakes. Gurbutt and Petrie (1995) applied these conservation principles to derive the mean water circulation.

The term "estuarine" is often used to characterize the pattern of circulation just described for a semi-enclosed area that has significant freshwater inflow. Accompanying this characteristic circulation of outflow in the upper layer and inflow in an underlying layer is a distribution of surface salinity that has the freshest water within the Lakes and increasing salinity towards the ocean. The sub-surface salinity follows the same pattern.

Mixing and Upwelling

Turbulent processes mix the surface layer waters with the sub-surface waters as they flow past each other; in the case of the mean circulation in the Lakes, the layers are moving in opposite directions. The fresher and generally warmer waters of the surface layer mix into the sub-surface layer causing it to warm and become less salty. At the same time, the sub-surface waters are mixed into the surface layer making it saltier and cooler.

Mixing enhances the estuarine circulation in the Lakes. If the less dense freshwater flowing into the Lakes was not mixed with the underlying saltier waters, it would simply flow out as a thin surface layer. The discharge into the Lakes would be balanced by the outflow to the ocean. Think of the freshwater as a dye. As mixing and consequently the salinity of the upper layer increases, the freshwater is effectively diluted by the saltier waters; therefore more of this diluted mixture must flow out into the ocean in order to balance the freshwater inflow. That is, the surface component of estuarine circulation must strengthen. By the same token, the underlying layer has lost salt to the upper layer, which must be compensated by inflow of salty water from the ocean.

Mixing can be caused by a number of mechanisms such as wind forcing, tides and bottom friction, and estuarine-induced current shear. Any mechanism that causes one layer of water to move at a different speed or direction than an adjacent layer is capable of generating mixing. On the other hand, a process, such a freshwater inflow, that increases the density contrast between surface and sub-surface waters will tend to suppress mixing. In fact, for freshwater inflow, there is a competition between the tendency to increase the vertical density contrast which inhibits mixing and the tendency to increase the velocity differences between layers that enhances mixing.

In their model of the Lakes circulation, Gurbutt and Petrie (1995) divided the vertical currents between 2 layers into 2 components. The first component, the "exchange" has equal values in both directions, i.e., as much water is mixed from the surface to the sub-surface layer as is mixed from the sub-surface to the surface layer. The second component represented a net flow from one layer to another: upwelling if it was from the sub-surface to the surface layer, downwelling if it was in the opposite direction.

The mixing between layers varies strongly throughout the Lakes as is indicated in Fig 3A. In this diagram, we have plotted the "exchange" between the surface and sub-surface layers divided by the volume of the latter. This gives a measure of the strength of the mixing from the surface to sub-surface layer. The strongest mixing by far occurs in the Great Bras d'Or Channel, where the intensity is about 100 to 150 times greater than in Whycocomagh Bay, East Bay and St. Andrews Channel, and 10-30 times more than in St. Patrick's Channel, West Bay, North Basin and Bras d'Or Lake. The primary factor that contributes to the strong mixing in the Great Bras d'Or Channel is the current associated with the semi-diurnal lunar tide. Gurbutt and Petrie (1995) also identified Barra Strait as another area where intense mixing occurs.

The mixing between the fresher surface layer and the sub-surface layer reduces the sub-surface layer's salinity; furthermore, because the sub-surface flow is inward from the ocean, some of the freshwater is carried back into the Lakes. Mixing also brings generally highly oxygenated water from the surface to the layers below. Other water-borne materials would behave in a similar fashion.

Two areas of the Lakes, North Basin and St. Andrew's Channel, have deep, isolated basins with depths exceeding 200 m. Gurbutt and Petrie (1995) incorporated these deep regions as distinct compartments in their model and derived the mixing rates that best fit the existing data (Fig 3B). The mixing in these areas is about 10 and 20 times less than the mixing between the surface and sub-surface layers in the Great Bras d'Or Channel. In these deep basins, the currents are generally weak, reducing the potential for vigorous mixing.

In addition to mixing between layers, there can also be a net flow from one to the other. As indicated earlier, if the flow is from the sub-surface layer to the surface layer, it is called upwelling, simply because of the upward transport of water. If the net flow is in the opposite direction, it is called downwelling. Fig 3C shows that in most areas of the Lakes, upwelling prevails and is strongest in North Basin and Bras d'Or Lake. It is somewhat weaker in the other areas. Whycocomagh Bay (east and west) is separated from St. Patrick's Channel by a shallow sill, which effectively isolates the deep areas of the Basin from the rest of the Lakes. This geometry strongly inhibits net flow from one layer to the other. For this reason, Gurbutt and Petrie (1995) assumed that the net flow from the sub-surface to the surface layer in Whycocomagh Bay was zero when they derived their circulation maps. It is evident that downwelling prevails in the Great Bras d'Or Channel (Fig 3C). According to the model, the vertical transport of water is greater in this region than in any other part of the Lakes.

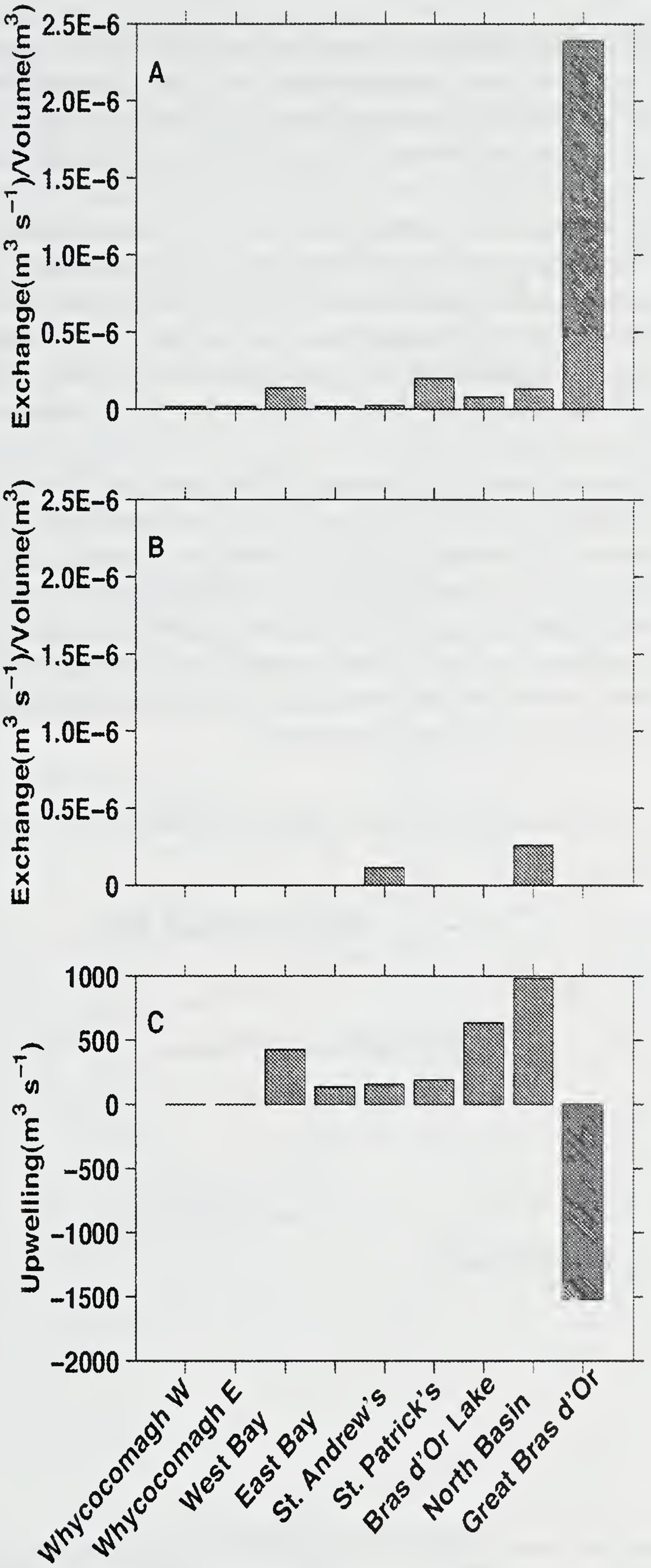

Fig 3 (**A**) Vertical exchange between the surface and sub-surface layers in the Bras d'Or Lakes. (**B**) Vertical exchange between the sub-surface and deep layers of the Lakes. (**C**) Upwelling (positive) or downwelling (negative) from the sub-surface to the surface layers of the Lakes.

Flushing Times

One way to establish 'flushing time' is to assume that a dye is put into an area of the Lakes. Allow the circulation and mixing that occur in the Lakes to dilute the dye until its average value reaches a predetermined level. In oceanography, this level is often set at 0.37 of the initial concentration. The time it takes to reach this value is called the flushing time.

Gurbutt et al. (1993) used their model of circulation and mixing to estimate the flushing times for the major regions of the Lakes. The longest flushing times of approximately 2 years were for the sub-surface layers in east and west Whycocomagh Bay, and about 260 days for the deepest basin in St. Andrew's Channel. The shortest flushing times of about 1.5 days were for the surface and sub-surface layers in the Great Bras d'Or Channel. These results are not surprising given the discussion of the mixing and upwelling above.

The decrease in concentration (beginning with a value of 1) over 300 days for the sub-surface layer of Whycocomagh Bay (west), and the deep layers of the North Basin and St. Andrew's Channel is shown in Fig 4. There is a relatively rapid rate of dilution at the start, followed by a more gradual decline. What are the implications of these results? Short flushing times can quickly disperse water-borne pollutants and keep a region of the Lakes well oxygenated. On the other hand, a long flushing time means that dilution of a water-borne contaminant occurs more slowly and that the supply of highly oxygenated waters to a region is reduced.

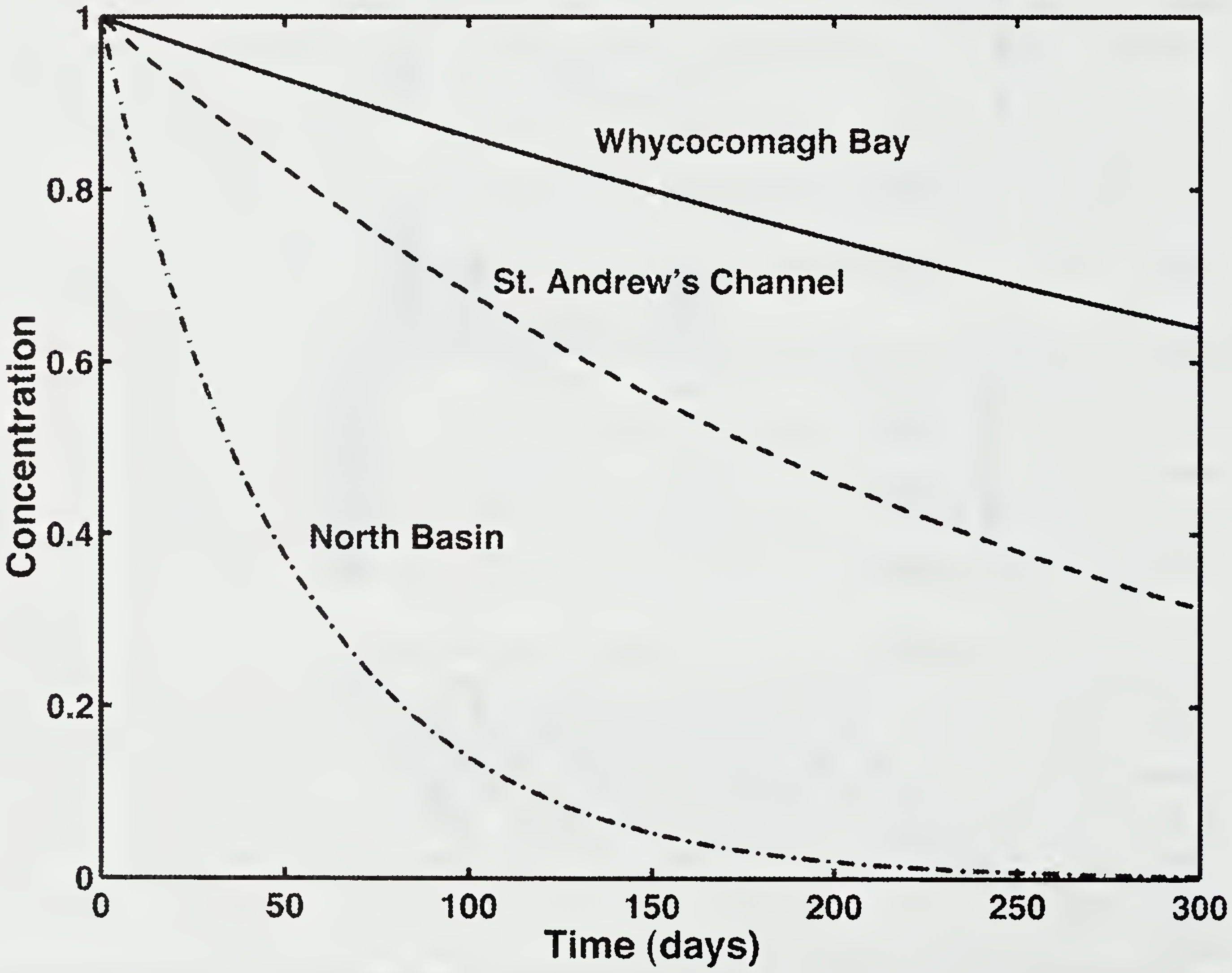

Fig 4 The change of concentration of a dye inserted into the deepest layers of the model of Gurbutt and Petrie (1995). Initial concentration was 1, all areas were run separately.

Gurbutt and Petrie (1995) considered the effects that flushing times would have on the oxygen concentrations throughout the Lakes. At a given temperature and salinity, there is a limit to the amount of oxygen that ocean water can hold in the dissolved form. At the maximum dissolved oxygen concentration, the water is said to be 100% saturated. However, at the surface, growing marine plants, wave action and turbulence will often lead to oxygen concentrations that exceed this level; the water is then super-saturated, i.e., exceeding 100%. Below the oxygen-rich surface layer, oxygen is depleted through fish respiration, benthic uptake (processes related to the bottom sediments), and oxidation of organic material in the water column. This last process is the most significant in the Lakes. On this basis, Gurbutt and Petrie (1995) predicted that the deeper half of both the eastern and western regions of Whycocomagh Bay would be anoxic, i.e, have no dissolved oxygen whatsoever. Oxygen concentrations in the deep areas of St. Andrew's Channel should be reduced by 20-50% and in the deep part of the North Basin by 5-15%. In fact, data have indicated that the deep part of the western half of Whycocomagh Bay was anoxic and probably has been in that state for a long time (Fig 5A). The eastern half of the Bay had concentrations reduced by as much as 70% of their maximum potential value, the deep areas of St. Andrew's Channel (Fig 5B) and North Basin were reduced by 20-45% and 5-10% of their maximum potential concentrations. These successful comparisons between model results and observations indicate that the model could be used to examine large scale, long-term pollution issues within the Lakes.

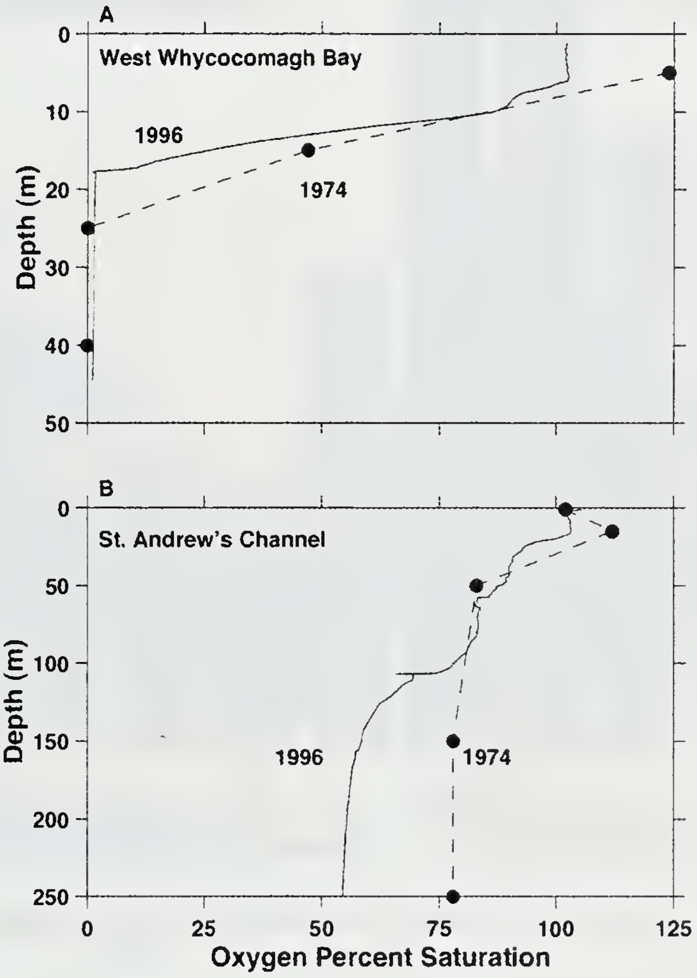

Fig 5 **(A)** Oxygen percent saturation variation with depth for the western half of Whycocomagh Bay. **(B)** Oxygen percent saturation for St. Andrew's Channel. Note the oxygen values for the 1974 data are from discrete samples and are determined by Winkler titration. The 1996 observations are from a YSI sensor mounted on the conductivity-temperature-depth (CTD) recording instrument.

Freshwater Inflow

One of the major forces that contributes to the circulation in the Lakes is freshwater inflow. The Lakes do not have a single dominant river source. Rather, there are a number of small rivers and brooks that supply the freshwater. In addition, the surface area of the Lakes is a sizable fraction of the land drainage area. Direct rainfall on the Lakes' surface and evaporation from it must be considered when determining the total inflow. Gurbutt *et al.* (1993) used gauged river inflow measurements, drainage basin areas and the area of the Lakes (for rainfall or evaporation) to determine an annual cycle of freshwater inflow. The annual cycle features a strong pulse of freshwater in the spring associated mainly with snow and ice melt and the tendency for greater rainfall during this season (Fig 6). The monthly average inflow in April and May reaches almost 250 $m^3 s^{-1}$. There is also a secondary peak in November-December of about 170 $m^3 s^{-1}$. The weakest inflow occurs during the summer months of July-September at a rate of just above 50 $m^3 s^{-1}$. This pattern of the annual cycle is typical of the eastern Canadian region.

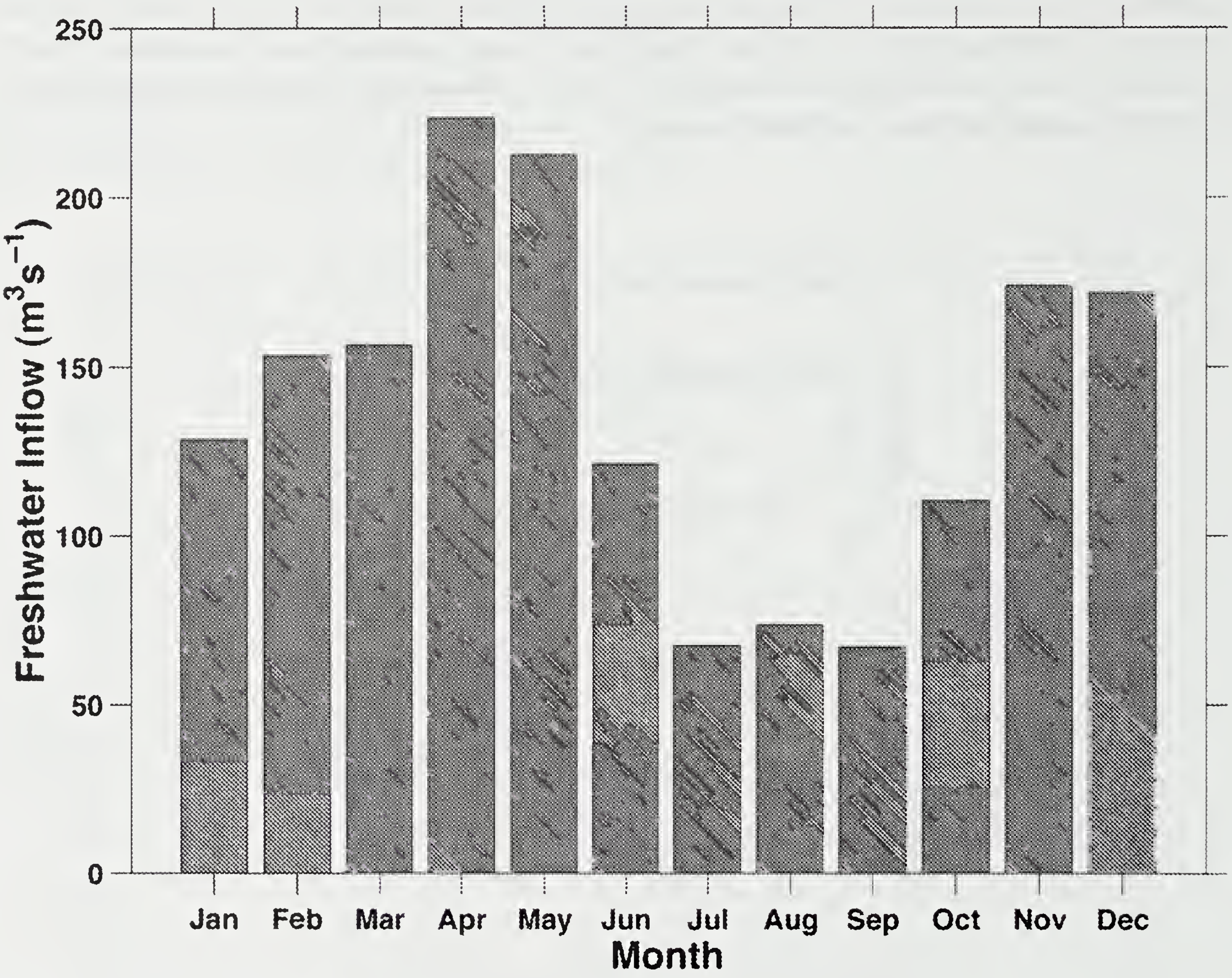

Fig 6 Monthly mean freshwater inflow into the Bras d'Or Lakes.

The overall magnitude of the freshwater inflow is small and would take nearly 7 years to replace the volume of water in the entire Lakes. Despite its relatively weak inflow, the freshwater does have a significant effect on the salinity of the Lakes as we shall see in the next section. This again relates to the restrictive connection between the Lakes and the ocean that controls the amount of saline water that can enter the system.

Distribution of Temperature and Salinity

The distributions of temperature and salinity in the Lakes for May and July are shown in Fig 7. The left side of each figure corresponds to Sydney Bight; moving to the right, the data come from the Great Bras d'Or Channel, the North Basin, through Barra Strait into Bras d'Or Lake and finish in East Bay. The locations of the stations are shown in Fig 1.

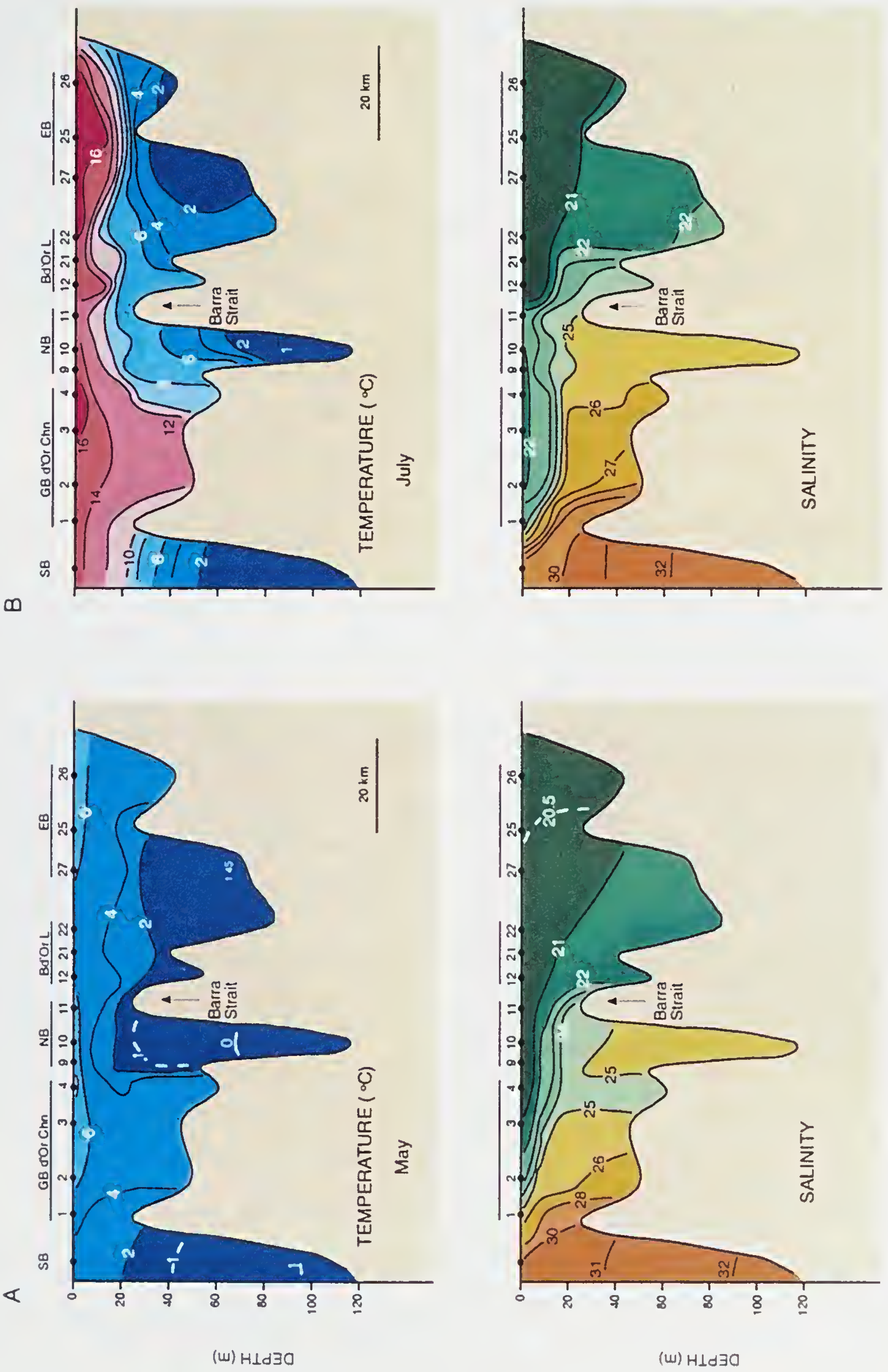

Fig 7 Temperature and salinity sections for the Bras d'Or Lakes **(A)** May 1974 and **(B)** July 1974. Sydney Bight (SB) is on the left hand side of each panel, East Bay (EB) on the right, with Great Bras d'Or Channel (GB d'Or Chn), North Basin (NB), Barra Strait, and Bras d'Or Lake (B d'Or L) in between. A line in Fig 1 shows the track of the line of stations. The position of each station where data were collected is shown as a dot and number at the top of each panel.

During winter, water temperatures fall to roughly 0°C in the Lakes. By May, surface temperatures are about 6°C, but the deeper waters remain close to 0°C. Temperatures in the Great Bras d'Or Channel show less change with depth than in other parts of the Lakes. This is probably because of the enhanced mixing in this region. Surface salinity in May changes significantly from Sydney Bight where it is about 30 (a salinity of 30 represents 30 gm of salt in 1 kg of seawater) at the surface, to less than 21 in North Basin, and 20.5 in East Bay. This surface salinity front (large change in a short horizontal distance) reflects the influence of the freshwater inflow into the confined area of the Lakes. Salinity at depth in North Basin is about 25. The average salinity of the Lakes is about 22, substantially less than an equivalent region in Sydney Bight. Given the volume of the Lakes though this adds up to a substantial quantity of salt, $7X10^{11}$ kg of salt.

Warming occurs through the spring and summer so that by July, surface temperatures can exceed 16°C. The change of temperature with depth increases for most of the Lakes but remains smallest in the Great Bras d'Or Channel. Temperature in the deep North Basin is less than 1°C and salinity is about 25.5. In East Bay, salinity has increased from its May values, perhaps because the inflow of freshwater has decreased from the spring runoff associated with snow melt and the general increase of rainfall at this time of the year. The influence of the limited exchange with the ocean manifests itself again as a strong change of salinity along the Great Bras d'Or Channel.

Another perspective of the temperature and salinity distributions in the Lakes is gained by examining those properties at a fixed depth (Fig 8). Two surveys, one in May 1974 and the other in September 1996 had sufficient spatial coverage to allow reasonable mapping of the temperature and salinity in approximately the upper 2 m over most of the surface of the Lakes. Some interesting features and contrasts are evident. Lower temperatures and higher salinities are seen at the mouth of Great Bras d'Or Channel for both surveys. In the September survey, the near-surface temperature was highest in St. Andrew's and St. Patrick's Channels, decreased into Bras d'Or Lake and was lowest in East Bay. It is possible that the low temperatures in East Bay were caused by upwelling driven by local winds when these measurements were taken. Also prominent is the decrease of salinity along St. Patrick's Channel into Whycocomagh Bay. A similar decrease, but not as large, occurs between North Basin and Bras d'Or Lake through Barra Strait. The lowest near-surface salinities were recorded in Denys Basin which is connected to Bras d'Or Lake through a very restricted passage. This restriction limits the influence of ocean waters in the Basin. In May 1974, the highest temperatures and the lowest salinities were found in Whycocomagh Bay at the head of St. Patrick's Channel. The central part of Bras d'Or Lake featured the lowest temperatures. Apart from St. Patrick's and the Great Bras d'Or Channels, the salinity differences were not large throughout the rest of the Lakes. The May 1974 survey did not make measurements in Denys Basin.

Infrared sensors on satellites provide estimates of sea surface temperature for the world's oceans. However the spatial resolution of these sensors is about 1 km, comparable to the widths of the channels in the Lakes. Thus the estimates of sea surface temperature for those areas are contaminated by land effects. We examined a broad range of sea surface temperature products and found that temperatures were only available for the central parts of the North Basin and Bras d'Or Lake.

How deep do the surface features in Fig 8 penetrate below the surface? For temperature and salinity it depends on the time of the year and on the location within the Lakes (e.g., see Fig 7). For the entire area of the Lakes, we calculated the monthly average depth where the temperature differs from the surface value by 1°C (Fig 9). We

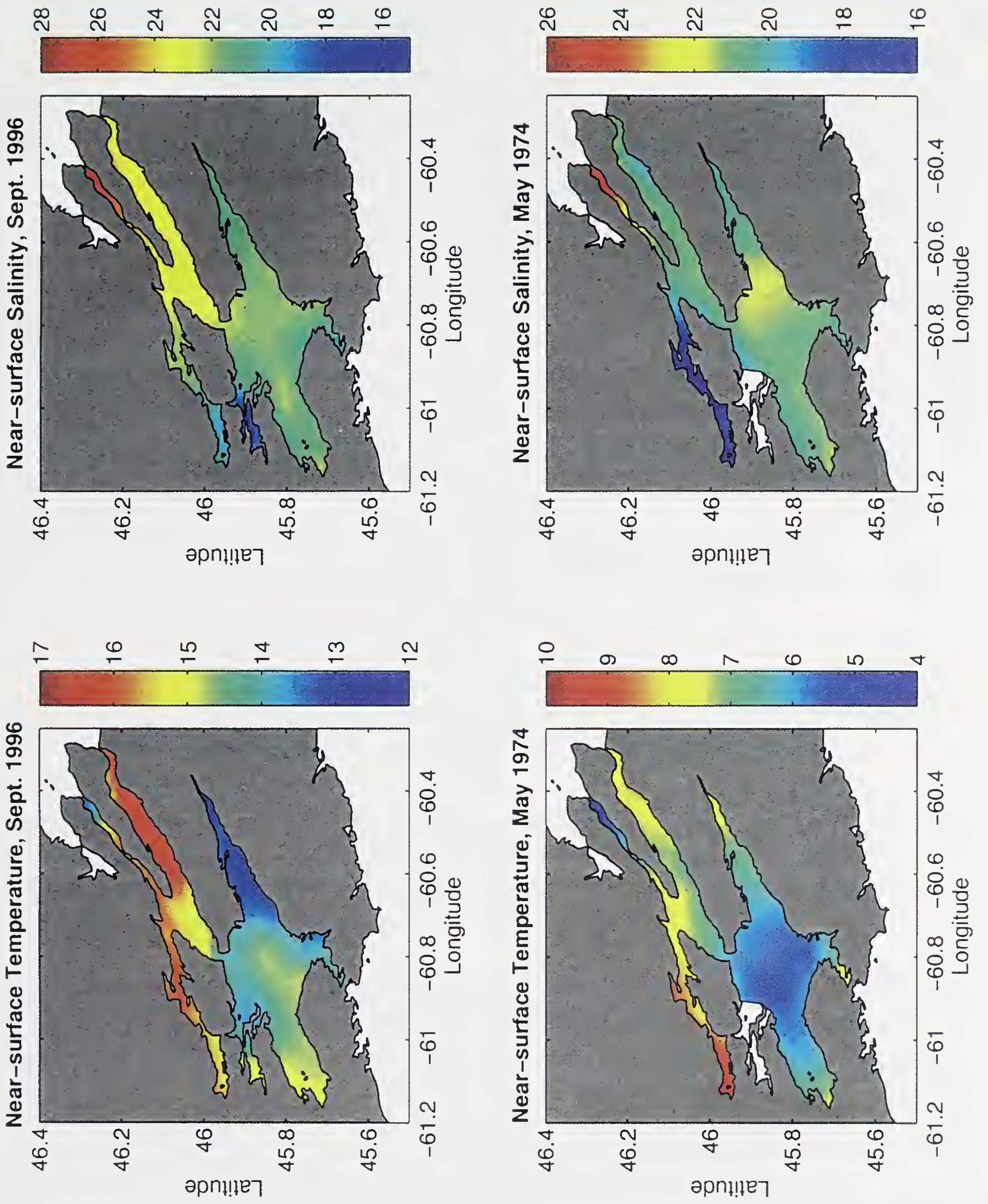
Near-surface Temperature, Sept. 1996
Near-surface Salinity, Sept. 1996
Near-surface Temperature, May 1974
Near-surface Salinity, May 1974
Latitude
Longitude
46.4
46.2
46
45.8
45.6
-61.2
-61
-60.8
-60.6
-60.4
17
16
15
14
13
12
28
26
24
22
20
18
16
10
9
8
7
6
5
4

Fig 8 Near-surface (approximately the upper 2 m) temperature and salinity from ship surveys in 1996 and 1974. Note that the colour scale changes for each panel and the white areas indicate no data were available to interpolate the temperature and salinity fields.

shall refer to this as the mixed layer depth. Data availability restricted the estimations to the May-November period. The results make sense when compared to other areas. In spring and summer we expect the mixed layer depth to be shallow because the heating from the sun is confined to the near-surface waters and winds are generally weak, thereby reducing the potential for turbulence. The mixed layer depth is about 4 m for the May to August period with a standard deviation of about 7 m (Fig 9). The

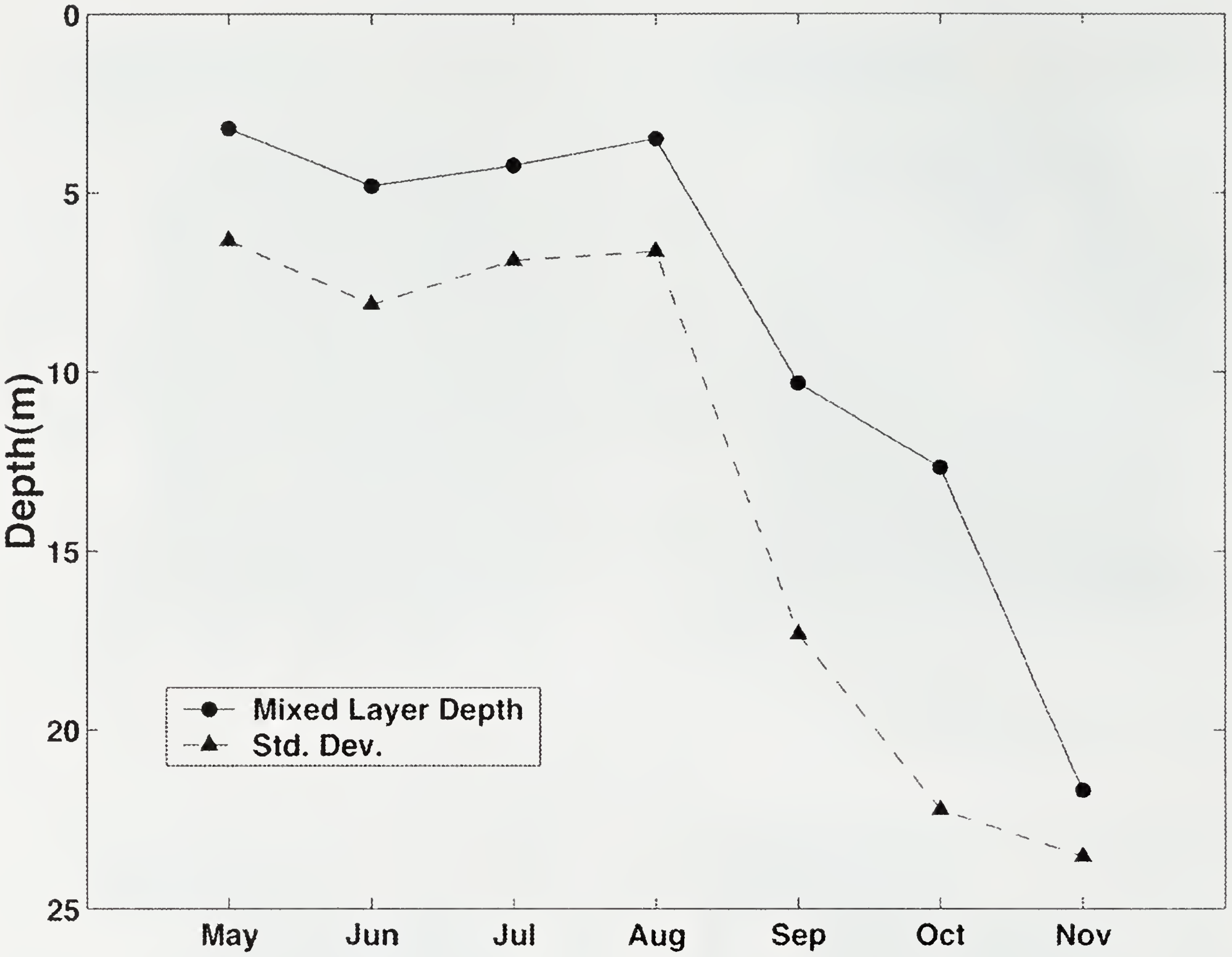

Fig 9 Depth of the mixed layer defined as the mean depth where the temperature changes by 1°C from the surface value. The standard deviation is also shown; it provides a measure of the scatter of the individual layer depths about the mean.

standard deviation indicates that there is significant variability of this depth throughout the Lakes, reflecting in part the tidal mixing, and consequently deeper mixed layers, that occurs in areas such as the Great Bras d'Or Channel and Barra Strait. Towards the end of the summer and in the early fall, solar heating decreases, and winds and the frequency of storms generally increase. Thus there is the potential to deepen the mixed layer. That is indeed what is observed (Fig 9). By November, the layer is on average about 22 m deep and still exhibits considerable variability, reflected in the standard deviation of about 24 m.

It is evident from Fig 7 that the temperature and salinity properties throughout the Lakes change markedly during the summer period. Continuous records from the Great Bras d'Or Channel and Barra Strait for 1998-99 (Fig 10), indicate that substantial changes occur during the year (see Fig 1 for locations). The salinity in the year-long record from Great Bras d'Or Channel ranges from about 22 to 29 (Fig 10A). With a maximum near-surface salinity daily change of 5; this gives a spiky appearance to the record. There are also longer term changes evident such as the overall decrease of salinity from winter to spring. This is related to the increased freshwater inflow in the latter period (Fig 6).

The cause of the rapid variations becomes evident when a shorter portion of the same record is examined (Fig 10B). The plot shows that there are approximately two large changes of salinity during a day. This variation is caused by the strong tidal currents

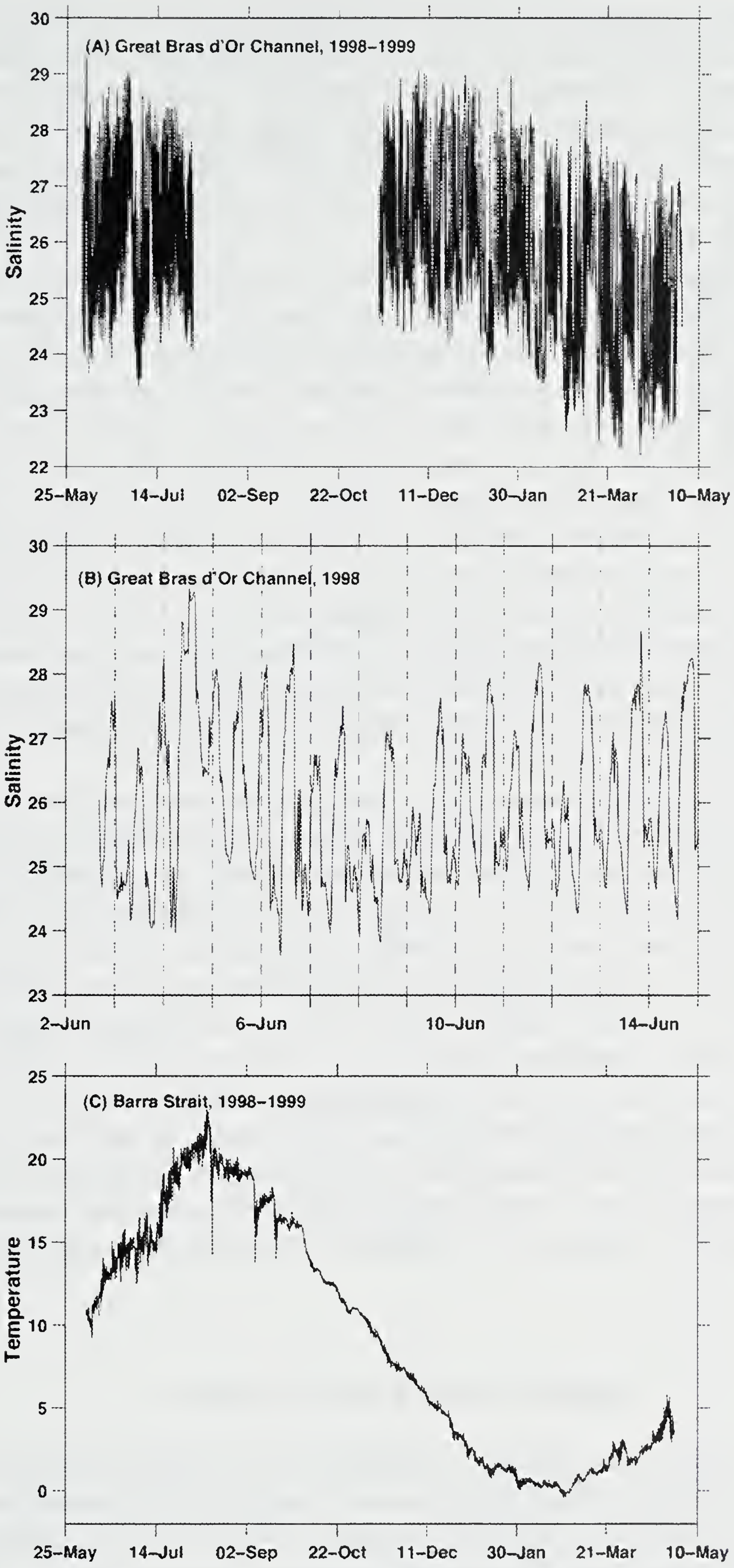

Fig 10 **(A)** Salinity time series from the Great Bras d'Or Channel. There are two records separated by a gap. The first record is from a depth of 4 m, the second from 3 m. **(B)** Start of the salinity time series shown in (A). **(C)** Temperature time series from Barra Strait. The first record, from 4 m, runs from June to early October,1998; the second, from 10 m, runs from October 1998 until April 1999.

moving the salinity front at the mouth of Great Bras d'Or Channel (Fig 7) back and forth past the sensor. On one part of the cycle, the sensor measures water whose properties are more characteristic of Sydney Bight; the flow then reverses and 6 h later the sensor measures water with properties shifted towards those of the Bras d'Or Lakes.

The annual cycle of temperature at Barra Strait for 1998-1999 is shown in Fig 10C. Peak temperatures of about 23°C were reached in mid-August and decreased to a minimum of about –0.25°C in late February.

Observations suggest that the changes in the deep basins are very small, even over periods as long as 75 y. In Fig 11 we show data from St. Andrew's Channel for depths equal to or greater than 100 m. The earliest observations are from 1924, the latest from 2000 with large gaps between years until the late 1990s. The data indicate that the temperatures range from –1 to 1°C with a median value of about 0.33°C; salinity has a range of about 24.8 to 26.5 with a median value of 25.43. The coolest temperatures and highest salinities are generally for the years 1924 and 1935. The warmest temperatures and the lowest salinities were for the years 1998-2000. These observations were compared to the variations of Sydney air temperatures and freshwater runoff from the nearby gauged Northeast Margaree River. The variations generally fit, high air temperatures led to high deep water temperatures, and low freshwater input led to high deep salinities and vice versa. These results indicate the importance of local processes, as well as inflow from Sydney Bight, in determining the properties of the deep waters of the Lakes.

There is a striking contrast between deep waters in the Lakes and the adjacent ocean. The temperature and salinity of waters at the same depth from the Laurentian Channel east of Sydney Bight, the nearest area with water depths comparable to St. Andrew's Channel, are about 5.8°C and 34.5. These values are substantially higher than the 0.33°C and 25.43 for temperature and salinity observed in St. Andrew's Channel. Two processes probably are most prominent in setting the deep water properties in the Lakes: local winter convection and advection, i.e. flow, from Sydney Bight with strong mixing occurring in the Great Bras d'Or Channel. During winter convection, cooling causes the near surface waters to become more dense than the waters below them. The denser waters sink and fill up the deep areas of the Lakes. Water from Sydney Bight is modified as it enters the Lakes through the Great Bras d'Or Channel and, if sufficiently dense, flushes the deeper areas of the Lakes, replacing the water that was present there. Currently a program is underway to determine the relative strengths of these two processes.

Currents in the Bras d'Or Lakes

Current observations were made by Krauel (1975a) during the Bras d'Or Lakes surveys in 1973 and 1974. Recording current meters were mounted on a mooring cable and suspended above an anchor by a sub-surface float. In the open areas of the Lakes, the currents were generally so weak that for a large percentage of the time no flow was registered. In the Great Bras d'Or Channel and Barra Strait, the currents were so strong that the moorings were tilted, a process that can lead to poor instrument performance and degraded data quality. In addition, depending on the strength of the current, the instruments would record at different depths: strong flows cause large mooring tilts, pushing the instrument deeper. This can make the data difficult to interpret.

In 1998-1999, bottom-sited acoustic Doppler current meters were moored in Barra Strait and just inside the mouth of the Great Bras d'Or Channel (Fig 1) These

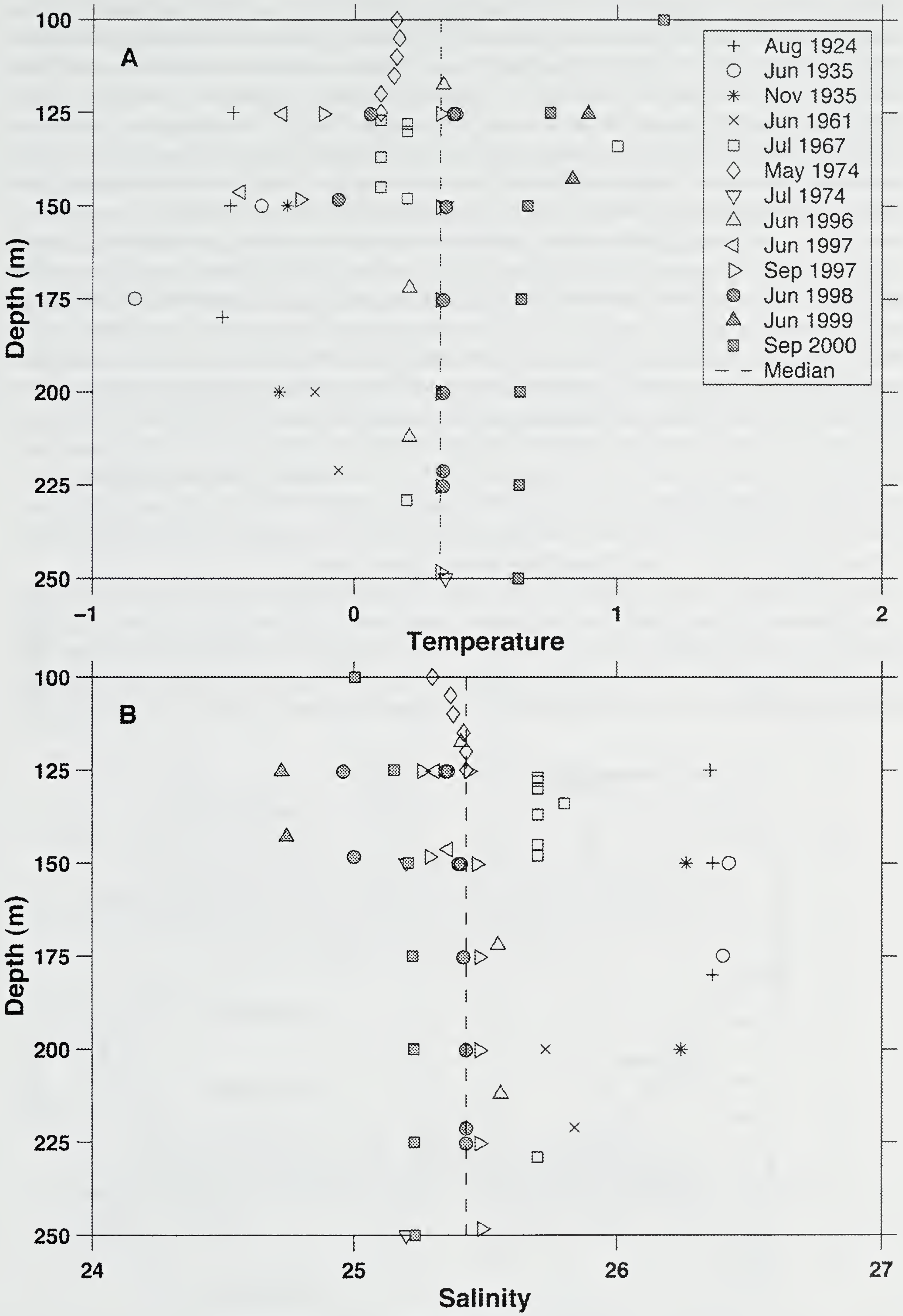

Fig 11 **(A)** Temperature and **(B)** salinity data from St. Andrew's Channel for depths equal to or greater than 100 m, spanning the years 1924-2000.

instruments sit on the bottom and measure the current by transmitting an upward pulse of sound and recording its echo reflected by small organisms and particles in the overlying water. If the echo has a higher (lower) frequency than the original sound, the reflecting particle is moving with the current towards (away from) the instrument. This change in sound frequency is known as the Doppler Shift. Four separate beams of sound are used so that the current speed and direction can be resolved. The return signals are processed in the instrument and estimates of the currents for each 1 m vertical interval are recorded. This instrument provides estimates of the current over most of the water depth without the problems that arise from tilting of ordinary meters.

A sample of the current records from the Great Bras d'Or Channel and Barra Strait illustrate the characteristics of the flow (Fig 12A, B; a negative sign means the water is flowing into the Lakes). At both locations a strong tidal component is evident as the rapid change of the along channel current approximately every 12 h (semi-diurnal) over the length of the record. The tidal component is considerably stronger in the Great Bras d'Or Channel with currents ranging from about –250 cm s^{-1} to about 150 cm s^{-1} (Fig 12A). The time series of current is biased towards the inflow side of the figure, i.e., most of the negative values are larger than the positive ones. This indicates that the average flow at this depth, 18.5 m, is into the Lakes. At Barra Strait the flows range from about –40 to 40 cm s^{-1}; however, at the depth (3.9 m) of this series, the bias is generally positive (Fig 12B), i.e. the 3.9 m flow is out of the Lakes.

These records run from the fall of 1998 to the spring of 1999. Fig 13 shows the mean, along channel currents and the amplitude associated with the tidal currents at both locations. In the Great Bras d'Or Channel, the mean flow is out of the Lakes at 4.5 m (Fig 13A). Below 4.5 m, the current is into the Lakes. The current meter is unable to estimate the flow in the upper 4 m because of inherent technical limitations. However,

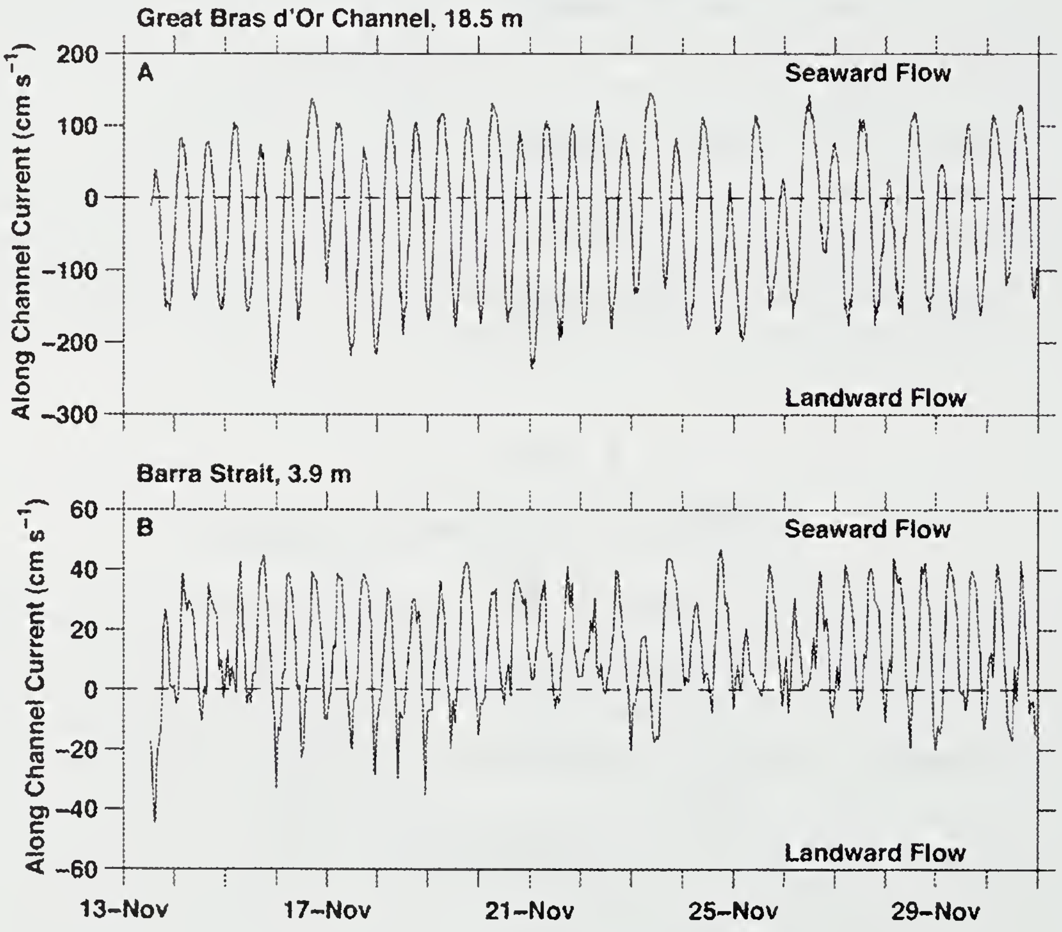

Fig 12 Current meter records from **(A)** 18.5 m depth inside the mouth of the Great Bras d'Or Channel and **(B)** from 3.9 m depth in Barra Strait in November, 1998. Note that a positive value indicates flow from the Lakes to the ocean and vice versa.

the flow in the 0-4 m range must be strongly out of the Lakes, otherwise they would fill with water and overflow the shore. As noted earlier, there must be a balance between inflow and outflow, in fact the outflow should exceed the inflow on average by the amount of freshwater that runs into the Lakes. On the other hand, at Barra Strait the mean flow is strongly out of the Lakes in the upper 14 m, 11 cm s^{-1} at 4 m depth. The flow then oscillates between positive and negative values from 15 to 44 m (Fig 13C). We think that the mean flow from 0 to 4 m is still out of the Lakes. The imbalance seen here indicates that we have not sampled the Strait adequately. It probably means that we should have had current meters at more locations across the Strait.

The semi-diurnal tidal amplitudes in the Great Bras d'Or Channel are about 90 cm s^{-1} at all depths (Fig 13B). There are a number of different tidal components that have periods of about 12 hours. The amplitude shown in the figure is the combined flow caused by all of the semi-diurnal components (discussed in more detail in the next section). The amplitudes are considerably smaller in Barra Strait, varying from about 5 to 20 cm s^{-1} (Fig 13D). The strong variation with depth is caused in part because the

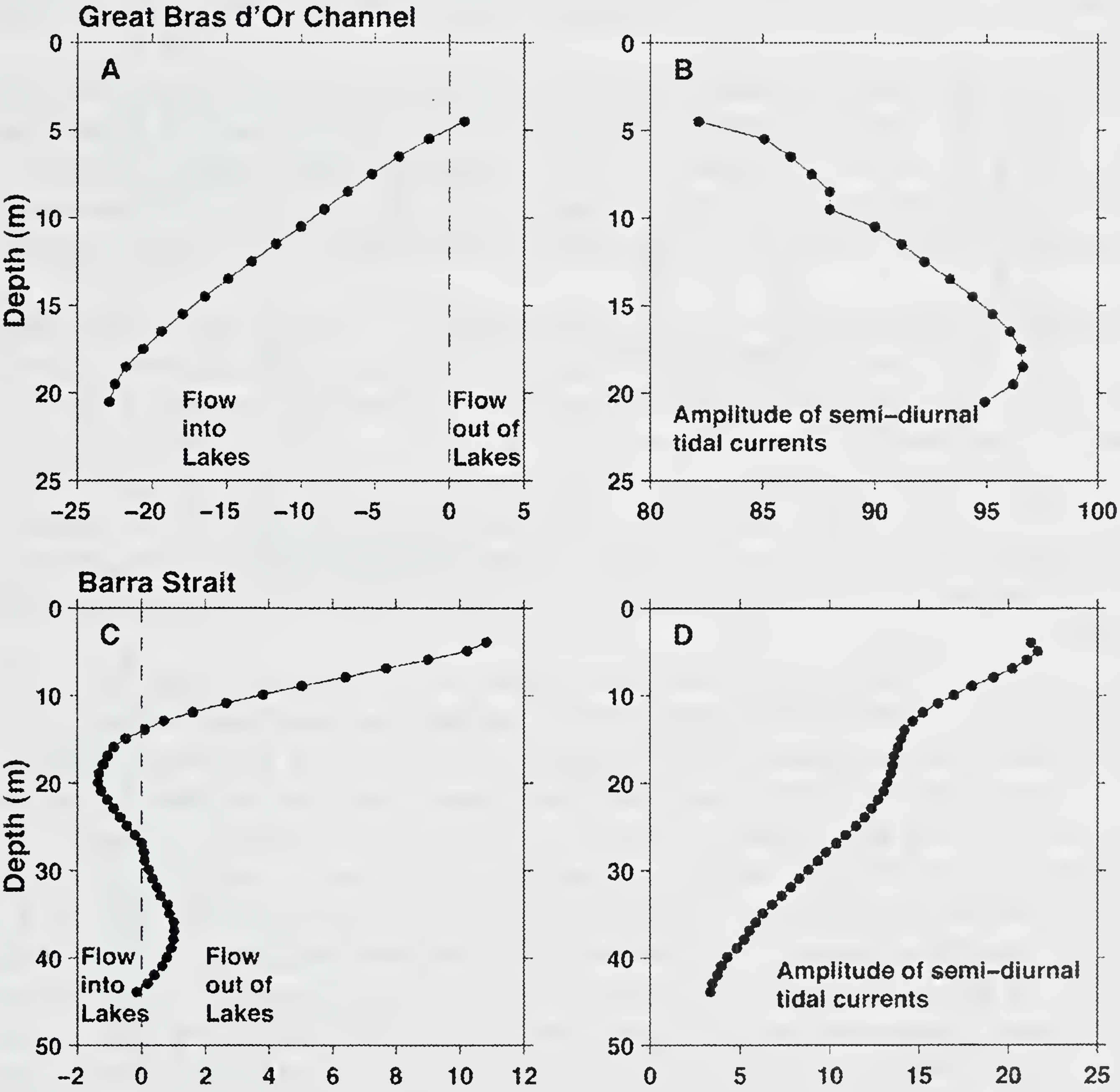

Fig 13 **(A)** Mean current along the channel axis for the period November 1998 – April 1999 for the Great Bras d'Or Channel. **(B)** Amplitude of the semi-diurnal tidal currents for the Great Bras d'Or Channel. **(C)** Same as (A) except for Barra Strait, October 1998 – April 1999. **(D)** Same as (B) except for Barra Strait, October 1998 – April 1999.

instrument was placed in a relatively deep hole in the middle of the Strait.

The currents in the Great Bras d'Or Channel are notable by any standard. The flows on occasion approach 3 m s^{-1}. In the Canadian east coast region, similar currents are generally only seen in the Bay of Fundy. These strong currents cause considerable mixing in the Great Bras d'Or Channel; the currents in Barra Strait, though weaker, still have the potential to generate significant mixing. Associated with the strong tidal currents are changes in sea level that have a distinct character in the Lakes.

Sea Level in the Bras d'Or Lakes

Tidal Elevations The effect of tides and the problem of sea level prediction in the Bras d'Or Lakes has intrigued the public for a long time. The Yachtsman's Guide to the Bras d'Or Lakes (1987) contains the interesting and puzzling statement: "tidal predictions ... are a matter of consternation. In a number of instances the lunar component of our semi-diurnal tidal area defies the 12-hour period by as much as 5 days at Barra Strait". Before dealing with this statement, we shall first indicate the dominant tidal component in the Lakes and also examine non-tidal influences affecting sea level.

The tides in the oceans are caused by the gravitational attraction of the sun and the moon. The orbits of the sun-moon-earth system follow complicated but predictable patterns that give rise to a number of tidal components with different periods of variability. The tides in the Bras d'Or Lakes are not the result of direct sun-moon gravitational forcing on the lake waters but rather are a response to the tides in Sydney Bight.

The tides in Sydney Bight have 5 major components (or constituents) that are called M_2, N_2, S_2, K_1, and O_1 with amplitudes of 36.8, 7.6, 10.9, 7.7, and 8.2 cm respectively. The first 3, known as semi-diurnal tides, have periods of roughly one half a day (i.e., they have 2 high and 2 low values each day), the last 2, called diurnal tides, have periods of approximately one day. The largest one by far is the M_2 tide (period 12.42 hours) which is the principal lunar constituent (the one mentioned by The Yachtsman's Guide to the Bras d'Or Lakes) and is caused by the moon's gravitational attraction on the world's oceans. We consider only this major component in the following discussion.

The amplitude of the M_2 tide decreases rapidly as it enters the Great Bras d'Or Channel (Fig 14A). The tide at Big Bras d'Or is reduced by more than one half (to 16 cm), compared to its amplitude at North Sydney of 36.8 cm. By Seal Island Bridge it has decreased again to 7.3 cm. The M_2 tide continues to decrease as it moves farther into the Lakes having amplitudes of 4 cm at Iona and 3 cm at Baddeck. There is no appreciable tide at Whycocomagh. In the Bras d'Or Lake, at Marble Mountain, Johnstown Harbour and Eskasoni, this component is remarkably constant at about 4.5 cm, slightly larger than in the North Basin. Not only does the amplitude of the principal component of the tides decrease as it enters the Lakes but the time of high water associated with it varies markedly relative to the tide at North Sydney (Fig 14B). In the Great Bras d'Or Channel, high water occurs earlier than it does at North Sydney by as much as 30 min. This lead is caused primarily by the strong frictional effects in the Channel (see Petrie 1999; Proudman 1953). At Baddeck and Iona the tide is approximately 3 h later than at North Sydney, and finally in the Bras d'Or Lake it is about 4 h later. Over most of the Lakes, the time of high water is considerably later than it is in North Sydney. Petrie (1999) modelled the M_2 tidal component and showed that friction and the geometry of the Lakes were the major contributors to the variations of tidal amplitude and timing.

Conceptually the response of the tides in the Lakes inside of Great Bras d'Or Channel can be thought of in the following way. In Sydney Bight, sea level associated with the M_2 tide is changing from high to low then back to high every 12.42 hours. Consider the case when the tide in the Bight is rising. This change enters the Lakes primarily through the Great Bras d'Or Channel. However, the Channel is narrow and generally shallow; in order to change the water level in the Lakes by the same amount as in Sydney Bight, the currents must be strong. As we saw in the last section, the currents are very strong in some places. But strong currents generate a lot of turbulence or friction as they flow over the rough ocean bottom. This friction opposes the flow of

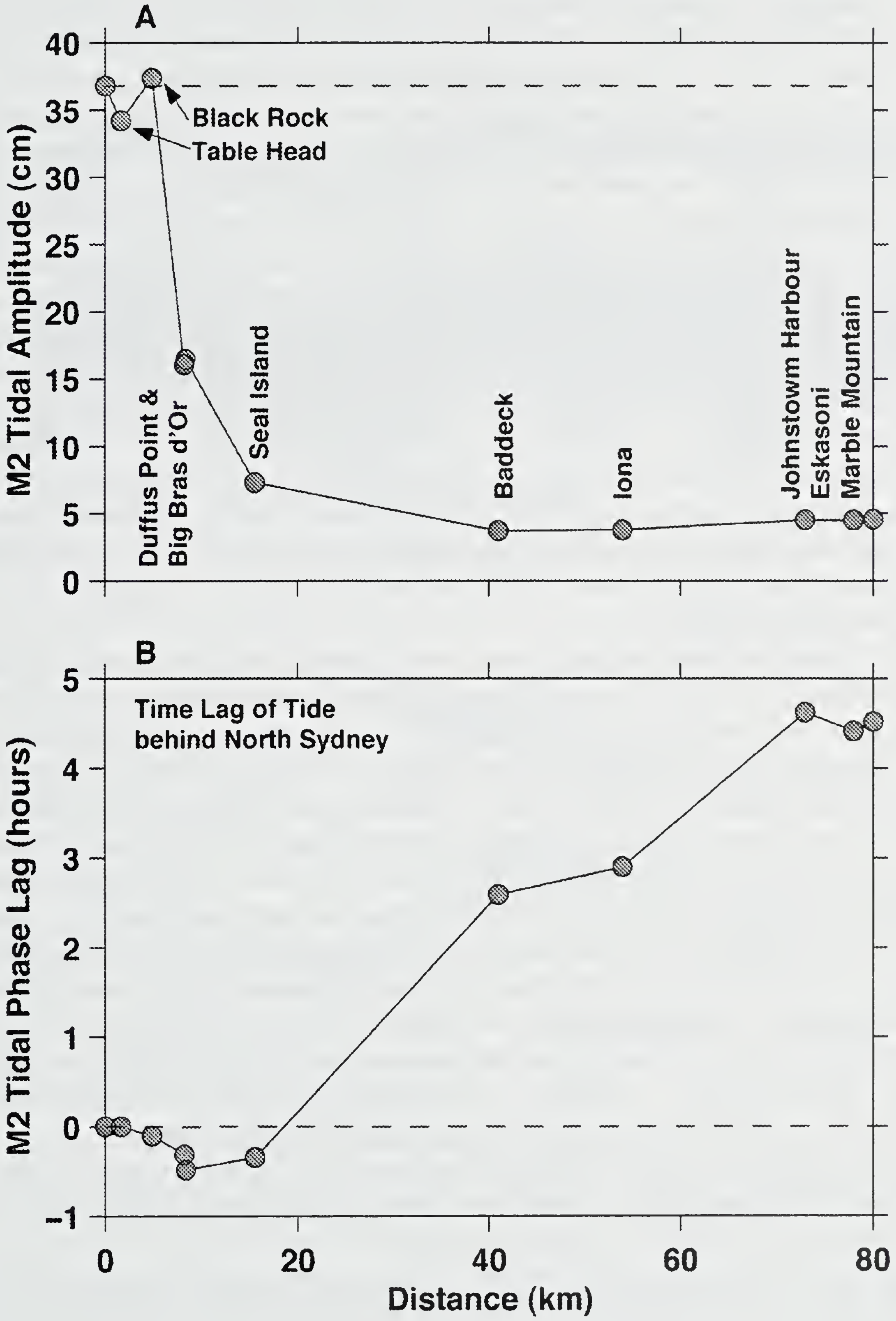

Fig 14 **(A)** Amplitude (cm) of the M_2 tide in Sydney Bight and progressively farther into the Lakes. **(B)** Delay (hours) of the tide behind high tide at North Sydney.

water into the Lakes causing a loss of energy; consequently, the tidal amplitude in the Lakes is not as large as it is in Sydney Bight. Even when sea level is starting to fall in Sydney Bight, it still can be higher than it is in the Lakes because the tidal amplitude there is not as large. Water will continue to flow into the Lakes, raising the sea level more. Therefore, high water in the Lakes will occur later than high water in Sydney Bight. When sea level in Sydney Bight falls below the level in the Lakes, the tidal currents will reverse and flow out of the Lakes.

Non-tidal Variations of Sea Level The tides are not the only cause of sea level variations in the Bras d'Or Lakes. Changes in atmospheric pressure, winds and sea level variations in the Gulf of St. Lawrence that move into Sydney Bight are also major factors. Atmospheric pressure changes over Sydney Bight were responsible for large fluctuations in sea level detected by the gauges that were moored in the Lakes in 1973 and 1974 (Petrie, 1999). The response of the ocean to atmospheric pressure changes is known as the inverted barometer effect because higher (lower) pressure leads to lower (higher) sea level. The time scales for these changes to occur are generally from several days to weeks. For the Bras d'Or Lakes, this mechanism works as follows.

High atmospheric pressure over Sydney Bight and the Bras d'Or Lakes region tends to push the water towards areas of the ocean where the atmospheric pressure is lower. Weather systems are generally large, so the low pressure region could be thousands of kilometers distant. It is however, easier to move water away from the Bight than from the Lakes because the Great Bras d'Or Channel restricts the movement of water out of the latter. Sea level thus falls first in Sydney Bight, leaving sea level in the Lakes higher. The difference in sea level causes water to flow from the Lakes into the Bight until a balance is reached. If, over the next few days, the atmospheric pressure in the region decreases, the process will reverse. Sea level will rise in Sydney Bight faster than in the Lakes, a sea level difference will be generated and water will flow into the Lakes through Great Bras d'Or Channel. Thus, sea level in the Lakes responds to sea level variations in Sydney Bight.

Fig 15A, B show sea level records from North Sydney and Seal Island. The tidal and non-tidal variations (Fig 15A) behave quite differently; the former, primarily made up of the M_2 tide and seen as the rapid, spike-like changes in the diagram, decreases markedly between Sydney Bight and Seal Island. As discussed above, they continue to decrease with distance into the Lakes. However, it is apparent that the non-tidal variations do not decrease much between North Sydney and Seal Island. This is more clearly illustrated in Fig 15B where the tides have been removed from the record. The more gradual changes seen in the North Sydney record decrease by a very small amount in the Great Bras d'Or Channel. In examining all of the records from the interior of the Lakes, Petrie (1999) found that the maximum reduction of the non-tidal variations (to be more precise, variations that have periods longer than 1 day) was about 15%. Therefore, the non-tidal sea level variations retain at least 85% of their magnitude as they move into the Lakes. Moreover, within the Lakes, these variations have been observed to be up to 50 cm, about 10 times larger than the tides.

The cause of much of the slowly-varying sea level changes seen in Fig 15B is apparent when the atmospheric pressure is compared to the sea level records. In Fig 15, the atmospheric pressure variations have been inverted; i.e. high values are plotted downward, low values are plotted upward. Most of the fluctuations seen in the inverted atmospheric pressure corresponds to the sea level data from North Sydney and the Lakes.

Why are the tides reduced so drastically yet the non-tidal variations pass into the Lakes largely unaffected? The key to understanding this is to recall how rapidly the variations occur. The tides change over a day (diurnal) or half day (semi-diurnal). For M_2, this means that sea level goes from its lowest to highest point in 6.21 h. In order for sea level in the Lakes to respond to these changes, water must flow very rapidly through the Great Bras d'Or Channel, first into the Lakes as sea level in Sydney Bight increases, then out as sea level falls. The friction that takes energy out of the tides is considerably more for currents with a high velocity than for those with a low velocity. (Technically if a current doubles, its frictional effect increases by four times.) Thus, friction becomes very important in decreasing the flow and the vertical movement of the sea surface. Consequently, there is a strong reduction of the elevation changes

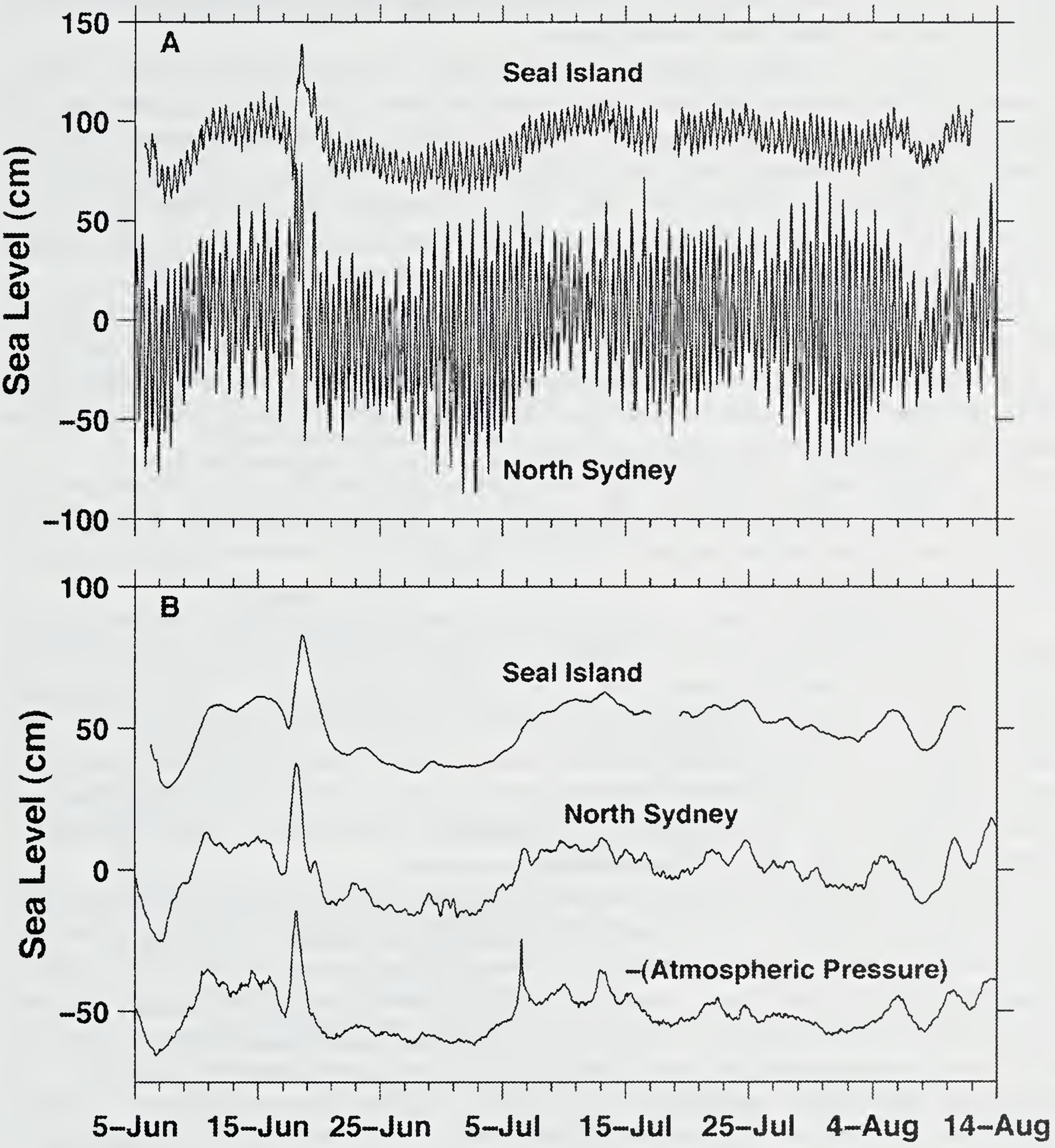

Fig 15 **(A)** Sea level records from North Sydney and Seal Island in 1973. **(B)** The same records after the tides have been removed. Also shown is the negative of the atmospheric pressure variation after the mean value has been subtracted, i.e. it is the inverted atmospheric pressure. Note in both figures the Seal Island record has been offset for clarity as has the atmospheric pressure in (B).

associated with the tides. On the other hand, sea level variations associated with non-tidal changes, such as from the inverted barometer effect, occur more gradually, over many days or even weeks (Fig 15B). The currents associated with these changes are much smaller than those associated with the tides since there is more time to move the water into and out of the Lakes. As a result, the frictional losses are not large and the sea level changes are only slightly smaller in the Lakes than they are in Sydney Bight. Petrie (1999) gives a more rigorous, mathematical explanation of this phenomenon.

Returning to the statement from "The Yachtsman's Guide to the Bras d'Or Lakes" we can speculate that the authors thought that only tides caused water level variations in the Lakes. They did not realize that non-tidal changes can be larger and vary more slowly. Perhaps they matched the highest predicted tide at North Sydney with the highest observed water level in the Lakes.

Surface waves Surface waves, the rapid vertical movement of the water's surface caused by wind, are another form of sea level variation. On the Lakes, their periods (the time between successive peaks or troughs at a fixed point) are primarily in the 2-4 second range. Environment Canada placed a wave rider buoy in the North Basin in 1992 and in the Bras d'Or Lake in 1993 (Fig 1). Both moorings recorded for about 6 months from the spring to the fall. Wave heights (the distance from the wave trough to its crest) were measured and their characteristics summarized every hour.

One of the parameters recorded by the buoys was the significant wave height (SWH). The SWH is determined by averaging the highest one-third of all the waves recorded in a specified time interval. Wave height generally increases with the strength of the wind, its duration, and with the distance that it blows over the water from land to the buoy site. This distance is called the fetch.

In the North Basin, the fetch for the dominant wind direction in the records was 11 km; in the Bras d'Or Lake, the fetch was 28 km. For the same wind strength and duration, we expect larger waves in Bras d'Or Lake than in the North Basin because of the former's longer fetch.

The results from the observation program are shown in Fig 16A, B. Note that the resolution of the SWH is 0.1 m, i.e., there are only values at 0, 0.1, 0.2 m etc. It is also traditional to use the wind speed in knots rather than metric units. The solid dots are the individual estimates of SWH, 3951 points in 1992 and 3891 points in 1993. The open circles connected by a line are the median values of wind speed plotted at every interval of 0.1 meters of SWH. The median is the value, such that half the values are greater, half are less. The broken line is the predicted relationship from a formulation of Bretschneider (e.g., Khandekar (1989)).

The waves in the North Basin are smaller than those in the Bras d'Or Lake for the same wind speed (Fig 16A, B). This is expected given that the fetch in the latter is greater. The idealized model gives qualitatively reasonable results but it generally overestimates the SWH in North Basin compared to the observations. In the Lake, the model agrees well with the observed median wave height. A more complete comparison would involve separating the wave parameters according to the wind direction. For each wind direction a separate model result would be calculated since the fetch changes and would be compared with the observed SWH. However, the relationships in Fig 16 can serve as a good guide for predicting the SWH in the Bras d'Or Lakes.

Ice Cover in the Bras d'Or Lakes

Over the past 3 years (1998-2000), the winters have been relatively mild and consequently ice cover over the Lakes has been below normal. On the other hand, we know that the flights of the Silver Dart relied on the ice of Baddeck Bay to serve as a runway for the first powered flights in the British Empire. It is apparent that ice cover varies substantially from year to year. Clearly a long time is required to collect enough observations to establish the average winter ice cover.

Environment Canada has been compiling ice statistics for the east coast since the early 1960s. We have used their maps of ice cover collected over 30 years to calculate the mean conditions for different areas of the Lakes. These have been combined to give

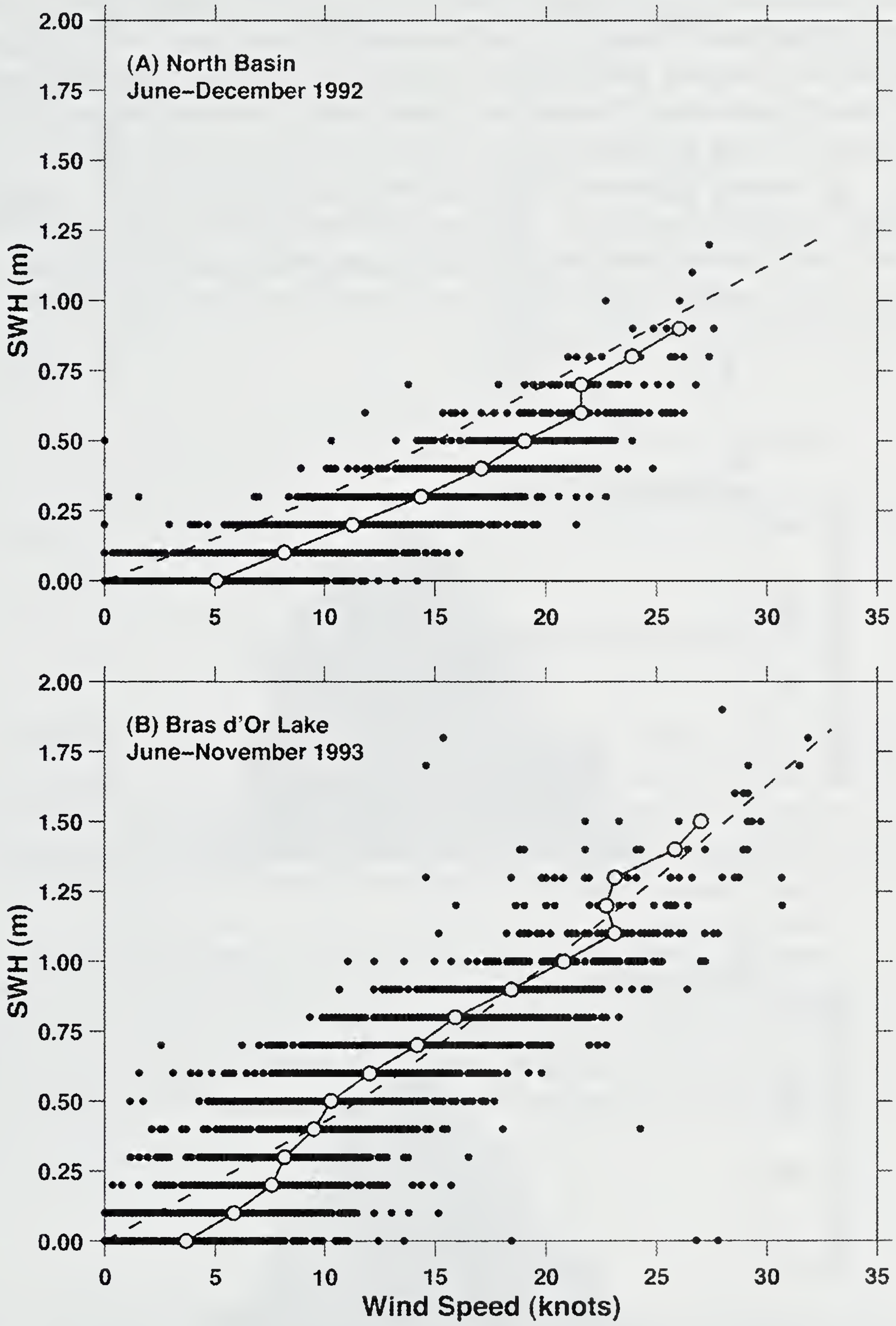

Fig 16 **(A)** Observed significant wave height (solid dot) for the North Basin as a function of wind speed. The medians of the observed values (solid line with open dots) and the predicted significant wave heights for a fetch of 6 nautical miles (broken line) are also shown. **(B)** Observed, median and predicted significant waves heights for a fetch of 15 nautical miles for the Bras d' Or Lake.

weekly estimates for the percentage of the areas north and south of Barra Strait that are covered by ice (Fig 17A, B). The areas north of the Strait include St. Patrick's, St. Andrew's and the Great Bras d'Or Channels, and North Basin; East and West Bays, Bras d'Or Lake and Denys Basin comprise the areas south of the Strait. On average, ice cover begins to develop in January in both regions, although there are occasions when some cover occurs in December. The peak is reached in early March, with generally greater cover for a longer period in the region north of Barra Strait. Ice cover begins to decease rapidly in April and has generally disappeared by the first week of May.

Variations occur from year to year as noted above. One might expect that the air temperature plays a fundamental role in the extent of ice cover. In Fig 18, we show the December to February temperature anomaly at Baddeck plotted against the February to March ice cover. During a normal winter, the temperature anomaly at Baddeck is zero, i.e., it is equal to its long-term average December to February temperature. A warmer than normal winter has a positive anomaly, a colder than normal winter a negative anomaly. Average winters generally give rise to 70% ice cover on the Lakes. For colder than normal temperatures (negative anomalies), cover generally increases, reaching 100% for some years. Warmer than normal winters typically have less than 70% ice cover.

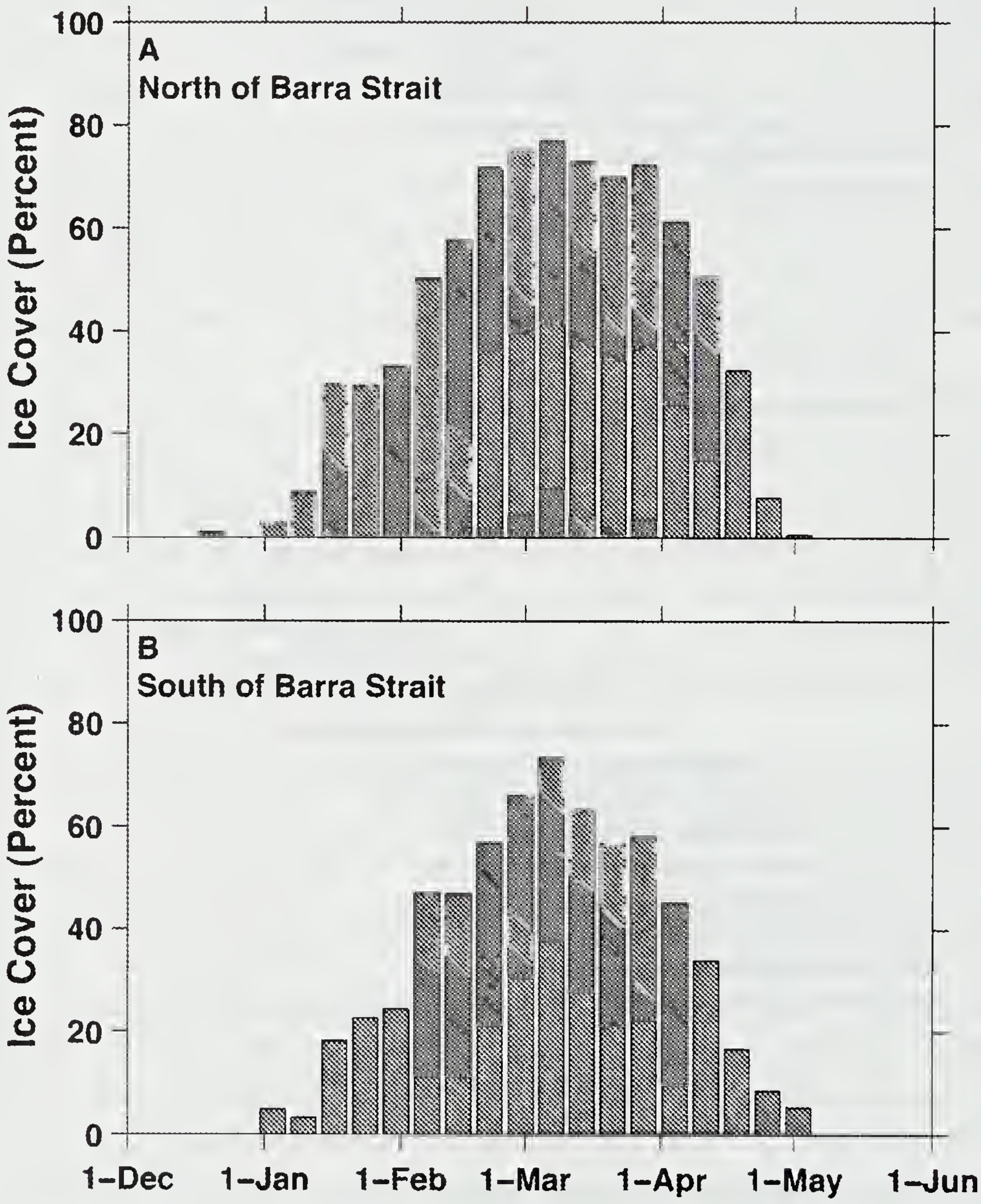

Fig 17 **(A)** Percentage of surface area north of Barra Strait covered by ice on average based on 30 years of data collected by the Atmospheric Environment Service. **(B)** Percentage of surface area south of Barra Strait covered by ice.

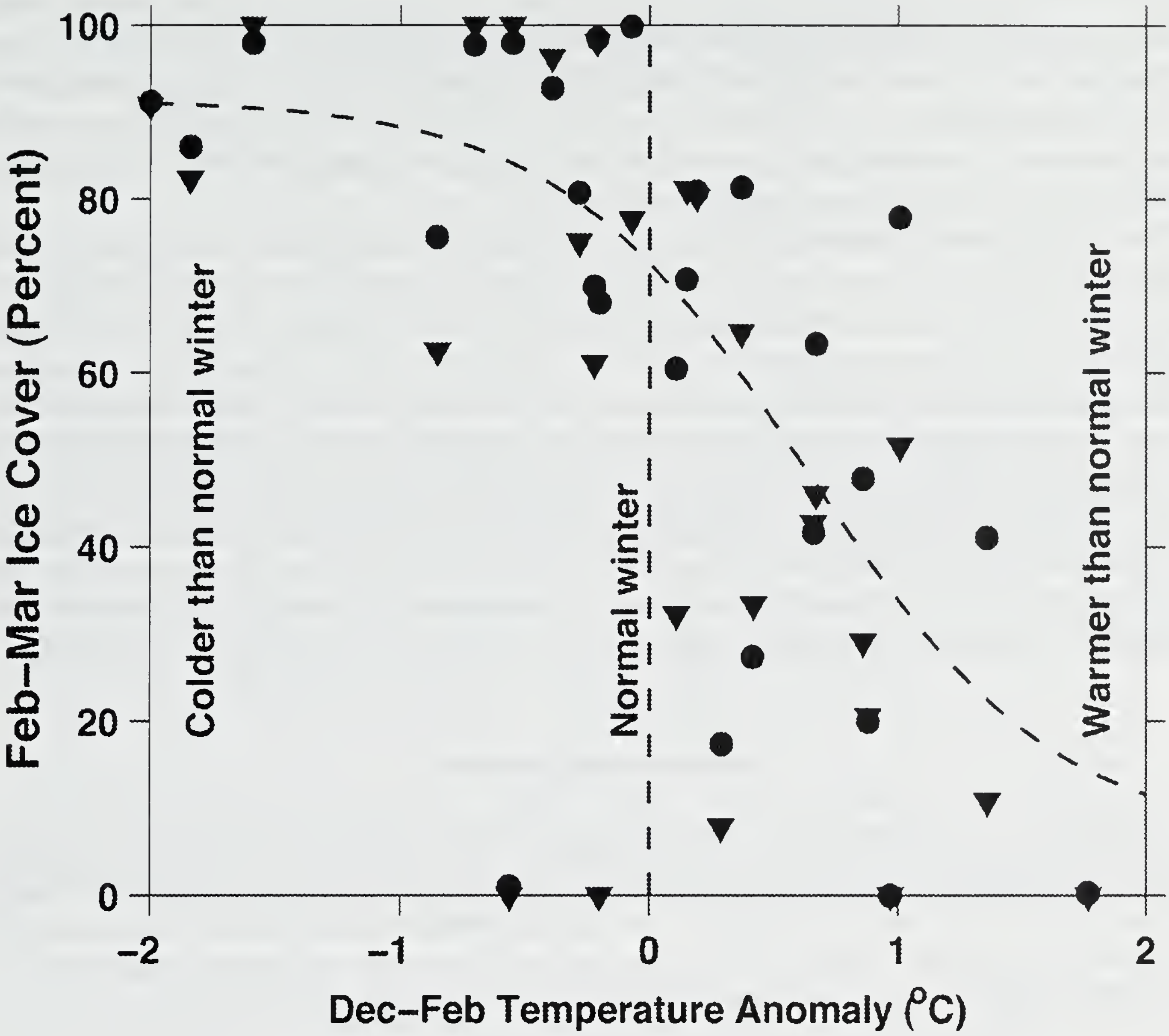

Fig 18 Winter (Feb-Mar) ice cover on the Bras d'Or Lakes (north of Barra Strait is represented by a triangle, south by a dot) compared to winter (Dec-Feb) air temperature anomaly at Baddeck. A temperature anomaly of 2 (-2) corresponds to 2°C above (below) normal. An average winter has an anomaly of 0°C. The broken line was fitted to the data to serve as a guide to the overall variation.

One factor that is missing from these data is ice thickness. During a colder than normal winter, ice cover can reach 100% but cannot exceed this value. However, for a very severe winter the ice thickness can significantly exceed the thickness during a winter that is only slightly colder than normal even though both may have 100% ice cover. The flight of the Silver Dart would not have been possible if the ice were only 1 cm thick.

Conclusions

From the analysis of archived data and the recent deployment of moorings we have learned a lot about the circulation, tides, mixing, temperature and salinity distributions, sea level, waves and ice cover in the Lakes. One of the major areas where knowledge has been lacking involves the winter circulation and convection that can occur because of the cooling of the near-surface waters. Comprehensive analysis of the data from the winter of 1998-1999 should help us understand the winter circulation. In the early fall of 2000, three moorings were placed in the Lakes, to explore the role that convection plays during the winter in mixing surface heat and salt to the deeper depths of the Lakes and in restoring oxygen levels to areas such as St. Andrew's Channel. These instruments will be recovered in the fall of 2001, redeployed for a final mooring period that will last until the spring of 2002. The data collected by this project will be valuable in our attempts to understand the workings of the Lakes during the winter. The analysis of these data will likely be completed in 2004.

The complicated patterns that we see in the current meter data collected in 1998-1999 will require a considerable modelling effort to arrive at an understanding. It is apparent from these data that the simpler models developed using the 1973-1974 data will not be adequate to explain the details of both the mean and the tidal circulation. However, these simpler models can be used to advantage to address multi-disciplinary issues. For example, the supply of nutrients through circulation and mixing could be estimated; the results could then be used to make estimates of primary production. The models could also be used as management tools to estimate the impact of pollutants or any water-borne variable on the Lakes. The combination of observations and modelling should continue to increase our understanding of the physical processes that affect the distribution of physical, biological and chemical variables in the Lakes.

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THE CHEMICAL OCEANOGRAPHY OF THE BRAS D'OR LAKES

PETER M. STRAIN[1] and PHILIP A. YEATS
Marine Environmental Sciences Division
Department of Fisheries and Oceans
Bedford Institute of Oceanography
Dartmouth, Nova Scotia, B2Y 4A2

Considerable research has been done on the Bras d'Or Lakes since the 1960s. Many of these studies have either focussed on chemical conditions in the Lakes, or have included chemical measurements in support of other research. Substances studied include major ions, inorganic nutrients, dissolved oxygen, chlorophyll, heavy metals and organic contaminants. What is known about the chemistry of the Lakes is reviewed and some model results are presented that combine what is known about the water circulation and external inputs of chemicals to estimate some parameters of biological productivity and to predict chemical distributions where data are currently unavailable. Overall, the low nutrient inputs to the Lakes can only support a relatively low level of natural biological productivity, and the contribution of sewage and other man-made sources of nutrients is very small. However, localized build-ups of both natural and anthropogenic nutrients have affected the water quality of some microenvironments in the Lakes, resulting in the eutrophication of sites like the west end of Whycocomagh Bay and some of the barachois ponds around the Lakes. Although the available data on contaminants are limited, there is no indication that any persistent organic or heavy metal contaminants are a concern within the Lakes. The environmental quality is in general very good. This status is a result of the small population density and the very limited industrial development around the Lakes. Maintaining or improving this status will require good management of current and future activities in the Bras d'Or Lakes and their watershed.

Depuis les années 1960, des recherches considérables ont été effectuées au sujet du lac Bras d'Or. Un bon nombre de ces recherches étaient axées sur les conditions chimiques dans le lac ou comportaient des mesures chimiques à l'appui d'autres études. Les substances étudiées comprenaient les principaux ions, les éléments nutritifs inorganiques, l'oxygène dissous, la chlorophylle, les métaux lourds et les contaminants organiques. On examine ici les connaissances dont on dispose au sujet des conditions chimiques du lac et on présente les résultats de certaines modélisations qui combinent nos connaissances sur la circulation de l'eau et les apports allochtones de produits chimiques dans le but d'estimer certains paramètres de la productivité biologique et de prédire la distribution des substances chimiques dans les cas où on ne dispose pas actuellement de données à ce sujet. De façon générale, le faible apport d'éléments nutritifs dans le lac ne peut alimenter qu'une production biologique relativement faible et la contribution des eaux usées et autres sources d'éléments nutritifs d'origine anthropique est minime. Toutefois, des foyers d'accumulation d'éléments nutritifs naturels et anthropiques ont influé sur la qualité de l'eau de certains micro-environnements du lac, ce qui a abouti à l'eutrophication d'endroits comme la partie ouest de la baie Whycocomagh et de quelques-uns des étangs-barachois alentour du lac. Quoique les données sur les contaminants soient limitées, rien ne révèle la présence dans le lac d'une contamination persistante par les matières organiques ou les métaux lourds qui donnerait matière à inquiétudes. La qualité du milieu est en général très bonne. Cela est dû à la faible densité de population et au développement industriel très limité alentour du lac. Le maintien ou l'amélioration de cette situation nécessitera une bonne gestion des activités actuelles et futures dans le lac Bas d'Or et dans son bassin hydrographique.

Introduction

The Bras d'Or Lakes (Fig 1) are a group of interconnected saltwater basins located in Cape Breton Island at the north-eastern end of Nova Scotia. They cover a total area of 1080 km^2, and have an average depth of ~30 m. There are a wide variety of physical environments in the Lakes. Some areas are shallow and flat-bottomed (e.g. Denys

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[1] Author to whom correspondence should be addressed

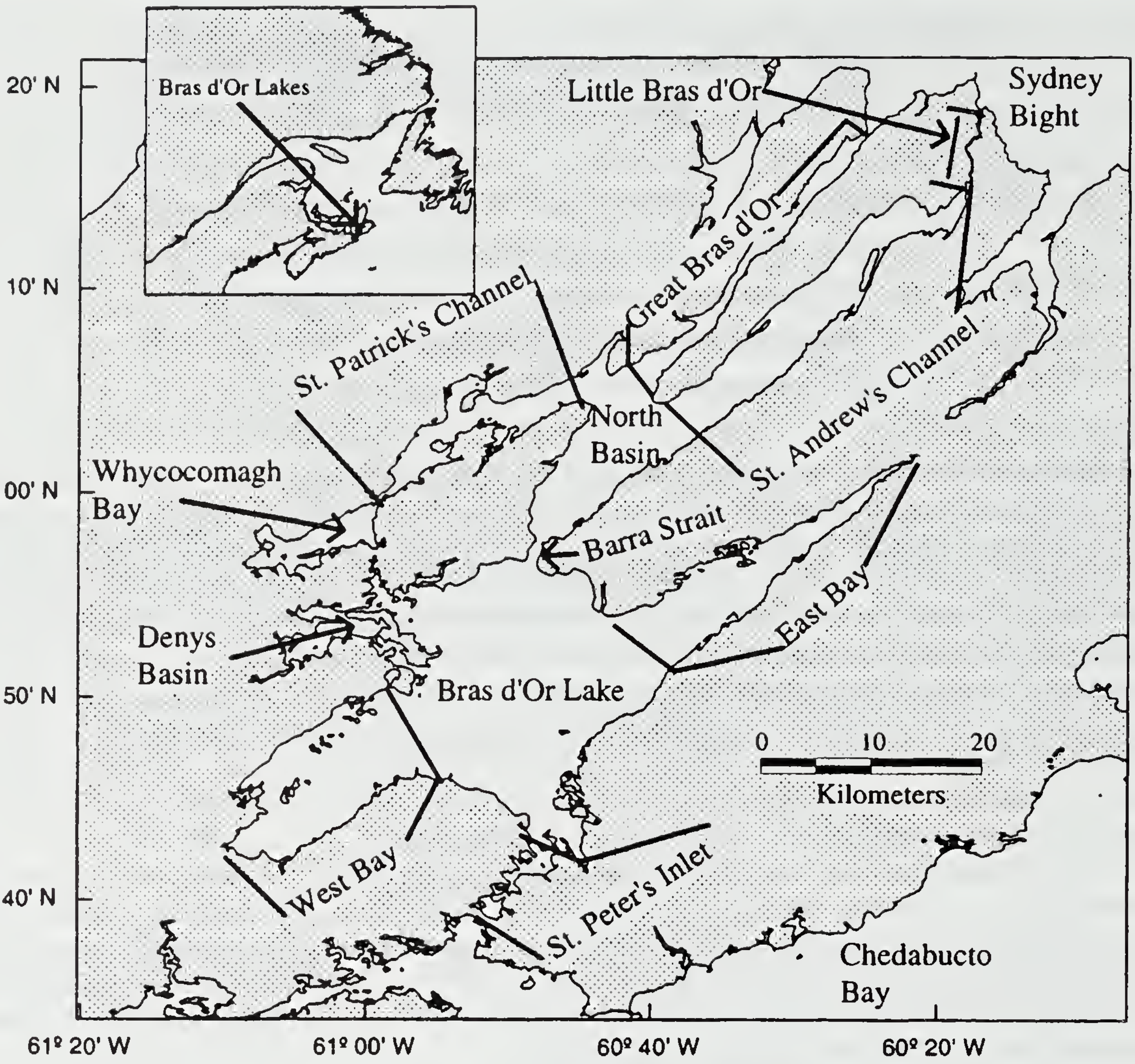

Fig 1 The Bras d'Or Lakes.

Basin, mean depth ~5 m); others are steep-sided and deep (e.g. St. Andrew's Channel, whose depths reach ~280 m). Small ponds that are partially or completely isolated from the Lakes by sand and gravel barriers are found along the shorelines. Locally, they are known as barachois ponds. There are 3 connections between the Lakes and the North Atlantic. There is significant exchange only through the Great Bras d'Or Channel, a long (~30 km), narrow (~1 km) channel that connects the Lakes to Sydney Bight, on the Nova Scotia side of Cabot Strait. The Great Bras d'Or Channel has an average depth of ~20 m and a maximum depth of ~95 m. A shallow (~12 m) sill near its mouth further restricts water movement into and out of the Lakes. There is negligible flow through the second permanently open connection to the Atlantic, the Little Bras d'Or Channel, which is located at the north-east end of St. Andrew's Channel. The third connection to the Atlantic is through a seasonally operated lock at the south-eastern end of St. Peter's Inlet that connects the Lakes to Chedabucto Bay on the Atlantic coast of Nova Scotia.

The complex geometry of the basins and embayments makes it necessary to consider processes that determine chemical distributions and behaviour on a number of different spatial scales. Chemical inputs and processes, and water circulation, mixing, and residence times are very different for some small bays and basins in the Lakes than they are for the Lakes as a whole. Within the Lakes, the different basins range in size from barachois ponds that are a few hectares in area and a few meters deep with volumes of $10^4 m^3$ to St. Andrew's Channel which has an area of approximately 13,000 hectares, depths up to 280 m, and a volume of $8.5 x 10^9 m^3$. Freshwater flows, which provide one pathway for the transport of both natural and contaminant chemicals into the Lakes, are also variable. The North Basin is about 6 times larger in area, and more than 20 times larger in volume, than the west half of Whycocomagh Bay, but the freshwater inputs into the 2 basins are approximately the same. Flushing time estimates vary from about one week in the Great Bras d'Or Channel to 40 weeks for the deep water of St. Andrew's Channel to 96 weeks for the deep water in the west end of Whycocomagh Bay (Gurbutt *et al.*, 1993). The intensity of vertical mixing in different areas of the Lakes also varies over a wide range (Gurbutt and Petrie, 1995).

It is important to understand the inputs of chemicals and their subsequent fates in coastal waters for a number of reasons. Inputs of nutrients may control the primary productivity of the Lakes' ecosystem, and the resulting growth and decay of organic matter will in turn determine the concentrations of dissolved oxygen that are available to support other marine life. Wastes from sewage, agriculture, aquaculture and other man-made sources add to these nutrient inputs and have the potential to alter both the natural concentrations and the ecosystem dynamics that depend on them. Enrichment of aquatic environments with dissolved nutrients is known as eutrophication. Other contaminants, such as heavy metals and persistent organic pollutants, also have the potential to affect the health of marine organisms and/or their suitability as food.

This article will review and discuss what is known about the chemistry of the Lakes, in terms of the inputs, distributions and dynamics of chemicals both in the Lakes as a whole and in the basins and embayments that make up the Lakes. It will also compare the chemical conditions in the Lakes to other marine environments in the region and use models of circulation and chemical behaviour to predict concentrations and transports.

Chemical Studies in the Bras d'Or Lakes. Sporadic interest in the Bras d'Or Lakes from the 1960s to the 1980s generated a number of studies of contaminants and the chemical oceanography of the Lakes. Young *et al.* (1959) measured the major ion concentrations in water, and concluded that the composition resulted from simple mixing between freshwater and coastal seawater, a conclusion supported by carbonate system and stable isotope measurements made by Mucci and Pagé (1987). Smith and Rushton (1964) measured dissolved oxygen levels in a number of the barachois ponds around the Lakes. Geen (1965) and Geen and Hargrave (1966) studied the primary and secondary production at a few sites, and made some measurements of nutrients, plant pigments and dissolved oxygen in support of this research. A large study of the suitability of the Lakes for aquaculture in 1972-73, summarized in Young (1976), included chemical measurements of heavy metals, nutrients, plant pigments and dissolved oxygen in molluscs, water and sediment samples from the Lakes and water and sediments from the influent rivers. Arseneau *et al.* (1977) measured a number of chemical parameters in surface waters in East Bay and the barachois pond at the northeastern end of East Bay, and dissolved oxygen profiles at one location in East Bay and several in St. Andrew's Channel. However, the technology Arseneau *et al.* were using was not well suited to making these measurements in salt water. Wright (1976) measured nutrients and plant pigments at a few locations from 1973 until 1975. Krauel (1975) made extensive physical oceanographic measurements, and included measurements of dissolved oxygen during one survey in July, 1974. Gurbutt and Petrie (1995) extended the analysis and interpretation of Krauel's physical oceanographic measurements, developed a box model describing water flow between different layers and basins in the Lakes, and examined the oxygen distribution and oxygen uptake rates. An Environment Canada survey of organic contaminants in the aquatic environment of the Atlantic Region in the late '70s and early '80s included results for water and sediments at a station in St. Patrick's Channel near Baddeck and the Baddeck River (Bailey and Howell, 1983; O'Neill, 1988; O'Neill and Kieley, 1992). In addition, Environment Canada's water quality monitoring program for contaminants in natural waters includes a number of stations in the Lakes and surrounding watershed.

During the 1990s a number of the gaps in our understanding of chemical conditions in the Lakes were addressed. Dalziel *et al.* (1998) measured the concentrations of a large number of chemicals, including nutrients and trace metals, in coastal rivers around the Maritime Provinces. This survey included spring, summer and fall measurements in 1994, 1995 and 1996 in the Baddeck and Middle Rivers, which flow through Nyanza Bay into St. Patrick's Channel, and River Denys, which is the principal freshwater flow into Denys Basin. Strain *et al.* (2001) conducted extensive surveys of the concentrations of nutrients, dissolved oxygen, and plant pigments and selected measurements of heavy metals in the Lakes from 1995 to 1997. Chou *et al.* (1999) measured metals in winter flounder and sediments from 5 locations in 1997. Willis (1999) measured levels of mixed-function oxidase activity, which is a response to exposure to contaminants, in winter flounder and organic contaminants (polychlorinated biphenyl compounds, PCBs, and polycyclic aromatic hydrocarbons, PAHs) in sediments from the same sites.

Nutrient Inputs to the Bras d'Or Lakes

The first studies of dissolved inorganic nutrients, oxygen and chlorophyll in the Bras d'Or Lakes focussed on freshwater inputs or areas very close to shore, sampling only a few offshore sites. For example, Smith and Rushton (1964) studied oxygen levels only in barachois ponds; Geen's study (1965) focussed on four sites in the open Lakes and one barachois pond; and Young (1976) concentrated on sampling the influent rivers, with a few sites in the Lakes. Since the surveys reported by Strain *et al.* (2001) provide extensive coverage of the major basins in the Lakes in 3 different seasons, they will form the basis of most of the discussion that follows. Generally good agreement was found among the different studies when data are available for the same locations and seasons, although some care must be used in interpreting the earlier data in the context of the analytical methods available at the time.

The biological productivity of an aquatic ecosystem may be determined by the available external supplies of the nutrients required for the growth of phytoplankton, provided that both light conditions and water column stratification are suitable for growth. Light intensity must be high enough to support photosynthesis and the water column must be sufficiently stratified to keep phytoplankton cells in surface waters with adequate light levels. Both of these physical factors are generally favourable for growth in the Bras d'Or Lakes. The median value of the attenuation factors for photosynthetic active radiation reported by Strain *et al.* (2001) was 0.20, showing that Bras d'Or waters are relatively clear for coastal waters (Kirk, 1983). Furthermore, the surface mixed layer is very shallow during the growing season in the Bras d'Or Lakes (3 – 5 m in the summer, deepening to 10-15 m in September and October, Petrie and Bugden, 2002). Given these favourable physical conditions, nutrient levels are most likely the factor controlling the surface layer productivity. The possible external sources of nutrients are rivers, atmospheric deposition (including precipitation), sewage, aquaculture and other man-made sources, and exchange with coastal waters in Sydney Bight. Estimates of these nutrient fluxes are shown in Fig 2. River inputs are derived from the data in Dalziel *et al.* (1998) for Cape Breton Rivers, weighted to account for the varying geology in the surrounding watersheds (Loring and Nota, 1973). Fluxes of nutrients in precipitation are based on data from GESAMP (1989). Sewage inputs are based on the population around the Lakes and typical *per capita* discharges for untreated sewage (Mueller and Anderson, 1983). Inputs from finfish aquaculture are calculated from estimates for total 1999 production from the Lakes

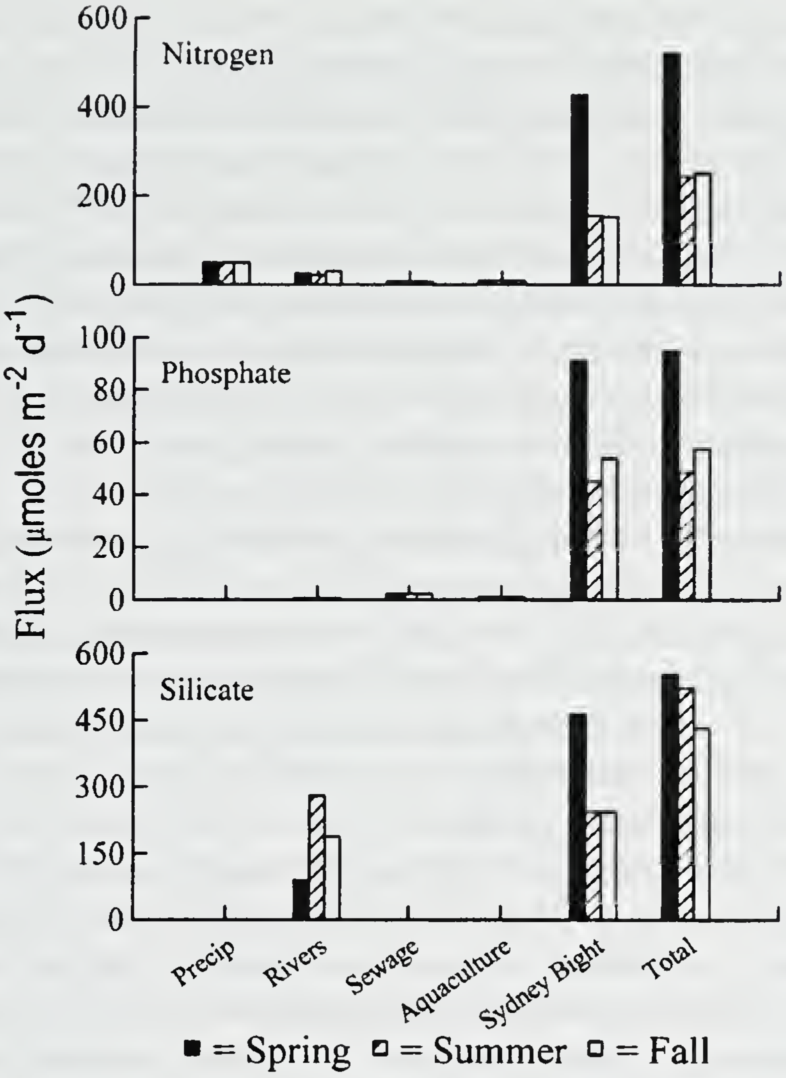

Fig 2 Inputs of nitrate + nitrite + ammonia, phosphate, and silicate to the Bras d'Or Lakes. Fluxes are given as the amount of nutrients entering the Lakes per day, averaged over the total area of the Lakes.

(Chandler, 2001) and estimates of loading from steelhead and salmon cage farm operations (Strain *et al.*, 1995; Ruohonen *et al.*, 1998). Inputs from Sydney Bight through the mouth of the Great Bras d'Or Channel are derived from the concentrations of nutrients in Sydney Bight (Petrie *et al.*, 1999) and the water flows from Gurbutt and Petrie's (1995) model of the circulation. The fluxes are reported as the amount of nutrient delivered per day to each m^2 of the Lakes, and represent conditions averaged over the entire Lakes ecosystem. The Sydney Bight fluxes are the inputs through the mouth of the Great Bras d'Or Channel, uncorrected for the export of nutrients in the outflowing surface water. The latter are generally small, because surface concentrations are low, except for silicate which is present at higher concentrations in the surface during the fall.

Inflowing water from Sydney Bight is the largest source of nitrogen and phosphate to the Lakes in all seasons (Fig 2). Lesser amounts of nitrogen but little phosphate are derived from precipitation and river inputs. River inputs are relatively more important for silicate, especially in the summer and fall. Also, there is more spatial variability in silicate than for nitrogen and phosphate: silicate concentrations are much higher in rivers that drain areas with mostly Triassic-Carboniferous rock formations, such as those areas that drain into St. Patrick's Channel, than in areas with mostly Cambrian-Devonian rocks, such as those areas that drain into East Bay. For example, the median silicate value reported by Dalziel *et al.* (1998) for the Middle River, which drains Triassic-Carboniferous land emptying into St. Patrick's Channel, was 68 µM; for the

Framboise River, which drains Cambrian-Devonian terrain adjacent to East Bay but actually discharges into the Atlantic, it was 1.1 µM.

Sewage inputs of nitrogen and phosphate are both very small compared to the natural fluxes into and out of the Lakes, and while these inputs may cause locally eutrophic conditions if the water circulation is restricted, they will have little impact on the Lakes as a whole. However, the faecal coliform organisms associated with sewage discharges do cause local closures of shellfish harvesting and may make some areas unsuitable for contact recreation. Nutrient inputs from finfish aquaculture are similar in size to those from sewage, but will be concentrated near the few farm sites. Inputs from aquaculture may also lead to local increases in nutrient levels, but do not pose the human health risks associated with domestic sewage.

Implications for Productivity. Phytoplankton growth requires nitrogen and phosphorus in a 16:1 ratio (in molar units), known as the Redfield ratio. N:P ratios in the inputs to the Lakes are 5.4, 4.6 and 2.7 in spring, summer and fall, strongly suggesting that nitrogen is the limiting nutrient in the Lakes. Nitrogen is also in short supply in the waters of Sydney Bight. N:P ratios through most of the year vary from 2 to 10; only in February do N:P ratios approach the Redfield ratio (Petrie *et al.*, 1999).

Since phytoplankton require carbon and nitrogen in a fixed ratio, and nitrogen is the limiting nutrient, the amount of 'new' primary production that could be supported by these net nitrogen inputs to the Lakes can be calculated. New production is that fraction of the total primary production that is due to external inputs, as opposed to production supported by the internal recycling of nutrients within the surface layer. The highest net input of nitrogen, 390 µmoles m^{-2} d^{-1} (this is the total nitrogen flux in Fig 2, corrected for the nitrogen exported through the mouth of the Great Bras d'Or Channel to Sydney Bight), occurs in the spring, and corresponds to a primary productivity of 2.6 mg carbon m^{-2} h^{-1} (average value for 12 h of growth each day). Similarly estimated production rates in summer and fall are 1.0 and 0.6 mg carbon m^{-2} h^{-1}, respectively. Another source of nitrogen for new production is the nitrate and ammonia stored in deep waters inside the Lakes, which are brought to the surface layer by vertical mixing processes. The water fluxes from Gurbutt and Petrie's model (1995) and nutrient data from Strain *et al.* (2001) can be used to estimate these vertical fluxes, and the production that they could support. The potential productivity due to this nitrogen source varies from 4.1 mg carbon m^{-2} h^{-1} in the spring to 4.3 and 5.7 mg carbon m^{-2} h^{-1} in the summer and fall. St. Andrew's Channel is the most important location for this supply, accounting for between 50 and 70 % of the total, despite the fact that the area of St. Andrew's Channel is only 12 % of the total area of the Lakes. Taken together, the external and deepwater sources can account for between 5.3 and 6.7 mg carbon m^{-2} h^{-1} of new production. Geen and Hargrave (1966) reported direct measurements of total primary production in the Lakes, over the late spring and summer, between 20 and 40 mg carbon m^{-2} h^{-1}. These estimates are equivalent if new production represents 15 to 30 % of the total production. These ratios are typical of those found in coastal waters at this time of year (Harrison, 2001).

The above estimates are appropriate for late spring, summer and fall production rates, but an additional source of nitrate is important during the spring bloom. Nutrients accumulate in the surface waters of the Lakes in the winter when light levels and temperatures are too low for the growth of phytoplankton. These nutrients are derived both from inflowing water from Sydney Bight (nitrate levels peak in Sydney Bight in January and February, and are 2-5 times greater than in April and May, Petrie *et al.*, 1999) and mixing between surface and deeper waters of the Lakes caused by winter cooling and storms. These accumulated nutrients both fuel, and are quickly removed by, the increased production rates that occur in the bloom. Although no direct observations of nutrient distributions in the Lakes are available for the winter period, it is possible to use the water circulation from Gurbutt and Petrie's model (1995) to estimate the winter build-up of nitrate. This estimate is an approximation, since the circulation model is based on spring to fall data. Using the same box structure as Gurbutt and Petrie (1995), and starting with observed fall nitrogen concentrations (Strain *et al.*, 2001), we simulated pre-bloom conditions by estimating the nitrate concentrations in the Lakes after 90 days without biological uptake. These calculations predict that the mean surface nitrate concentration would increase from 0.3 to 4.9 µM, similar to the few reported winter measurements. Wright (1976) reported maximum nitrate levels of 6.5 and 5.4 µM for Baddeck and Nyanza Bays, respectively. For a bloom that spans a two week period, the nitrogen inventory predicted by the model for the top 20 m would support an average new production rate of 27 mg carbon m^{-2} h^{-1}. Overall, these calculations indicate that new production during the spring bloom could be supported mostly by nutrients accumulated in the surface layer over the winter, but that nutrients from deep waters within the Lakes dominate later in the growing season, when the rate of new production is much lower.

Almost all of the nitrogen available for new production in the Lakes is supplied from marine sources, either Sydney Bight or the deep waters of the Lakes. An even higher percentage of the phosphorus supply is derived from these sources. Only for silicate are land based sources significant. Silicate supply will not affect the overall potential for new production, but it will determine the abundance of diatoms, which are an important group of phytoplankton which require silicate for growth. Since silicate inputs from land sources are spatially variable around the Lakes, there may also be variations in the relative abundance of diatoms in different lake basins.

Table I External sources of inorganic nitrogen (nitrate + nitrite + ammonia) to inlets in Maritime Canada (µmoles m^{-2} d^{-1}).

	Bras d'Or	Ship Hbr[1]	Halifax Hbr[2]	Kouchibouguac[1]	Letang[3]
Precipitation	50	50	50	50	50
River Inputs	26	530	230	140	92
Marine Exchange					
In	245	2130	318	~ 3330[4]	~ 48000[4]
Out	125	1710		~ 2040[4]	~ 48000[4]
Net In	120	420		~ 1290[4]	???
Sewage	8	< 1	1780	< 1	32
Industrial					
Fish processing					520
Finfish Aquaculture	9				4130
Pulp & Paper					12

[1] Strain, unpublished data.
[2] Petrie and Yeats (1990).
[3] Strain et al. (1995).
[4] Marine exchange difficult to quantify with existing data.

Comparison of Inputs with those for Other Maritime Coastal Waters. Table I compares the average annual nitrogen inputs to the Bras d'Or Lakes with those to other inlets of various types in the Maritime provinces. As in Fig 2, the data are reported in terms of daily delivery of nitrogen, normalized to the area of the inlets. Ship Harbour is a relatively pristine inlet on the Atlantic coast of Nova Scotia. Halifax is the largest population centre in the Maritimes: raw sewage from approximately 350,000 residents, as well as industrial wastes, are discharged into its harbour. Kouchibouguac is a barrier beach inlet in a National Park on the New Brunswick Gulf of St. Lawrence shore. The Letang is an inlet on the New Brunswick Bay of Fundy coast whose industries include intensive Atlantic salmon aquaculture, fish processing and pulp and paper.

Although these calculations are approximate, they do suggest that the Bras d'Or Lakes are quite different from these other inlets in several ways. River inputs of nitrogen to the Bras d'Or are the lowest of any of these locations, due to both the relatively small freshwater discharges and the low concentrations of nitrogen in those discharges. With the relatively small size of the river and marine inputs, precipitation to the Bras d'Or is relatively more important than in the other systems. Although the net marine exchange is an important fraction of the total external nitrogen input to the Lakes (as it is for some of the other inlets), it is the smallest value found in this group of inlets. The total nitrogen inputs are very much smaller than to any of the other inlets, which may explain why the Lakes have been described as a 'relatively unproductive body of water' (Geen and Hargrave, 1966).

Nutrient and Chlorophyll *a* Distributions in the Bras d'Or Lakes

The nutrient distributions in the Bras d'Or Lakes, as in all water bodies, are determined by inputs, biological processes and water circulation. Strain *et al.* (2001) report measurements from all of the lake basins; Fig 3 is a composite map of station locations they sampled from 1995 to 1997.

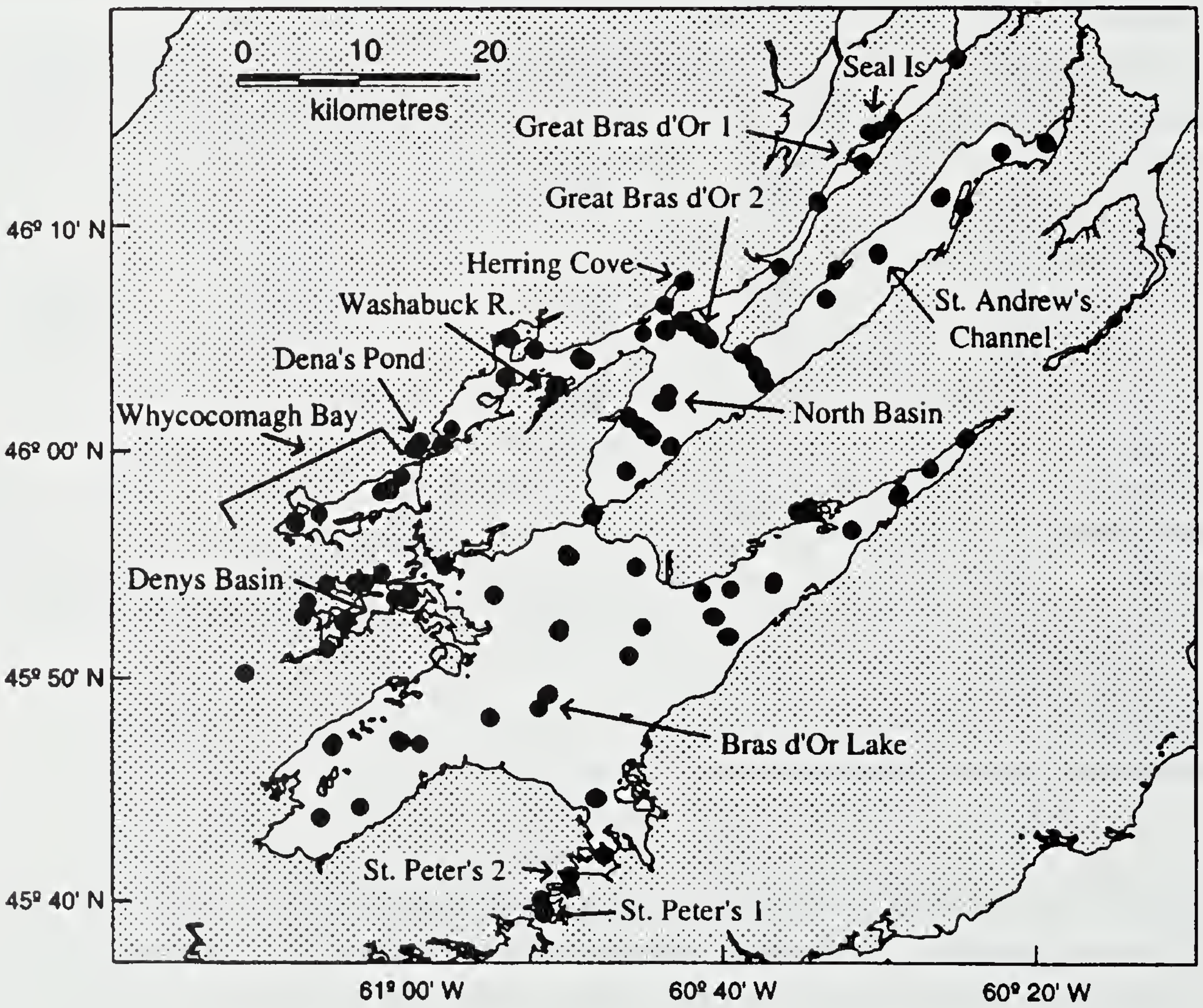

Fig 3 Stations sampled from 1995-1997 (Strain *et al.*, 2001).

Surface Distributions. The histograms in Fig 4, 5 and 6 show the range of values for the nutrients, chlorophyll *a* and dissolved oxygen in the Lakes during the spring (April 25 – May 1), summer (July 7-11) and fall (Sept. 22-27) of 1996 for the top 15 m of the water column. This depth range is used to illustrate conditions in the surface layer without introducing data from bottom waters of some of the shallower basins in the Lakes which might obscure surface processes.

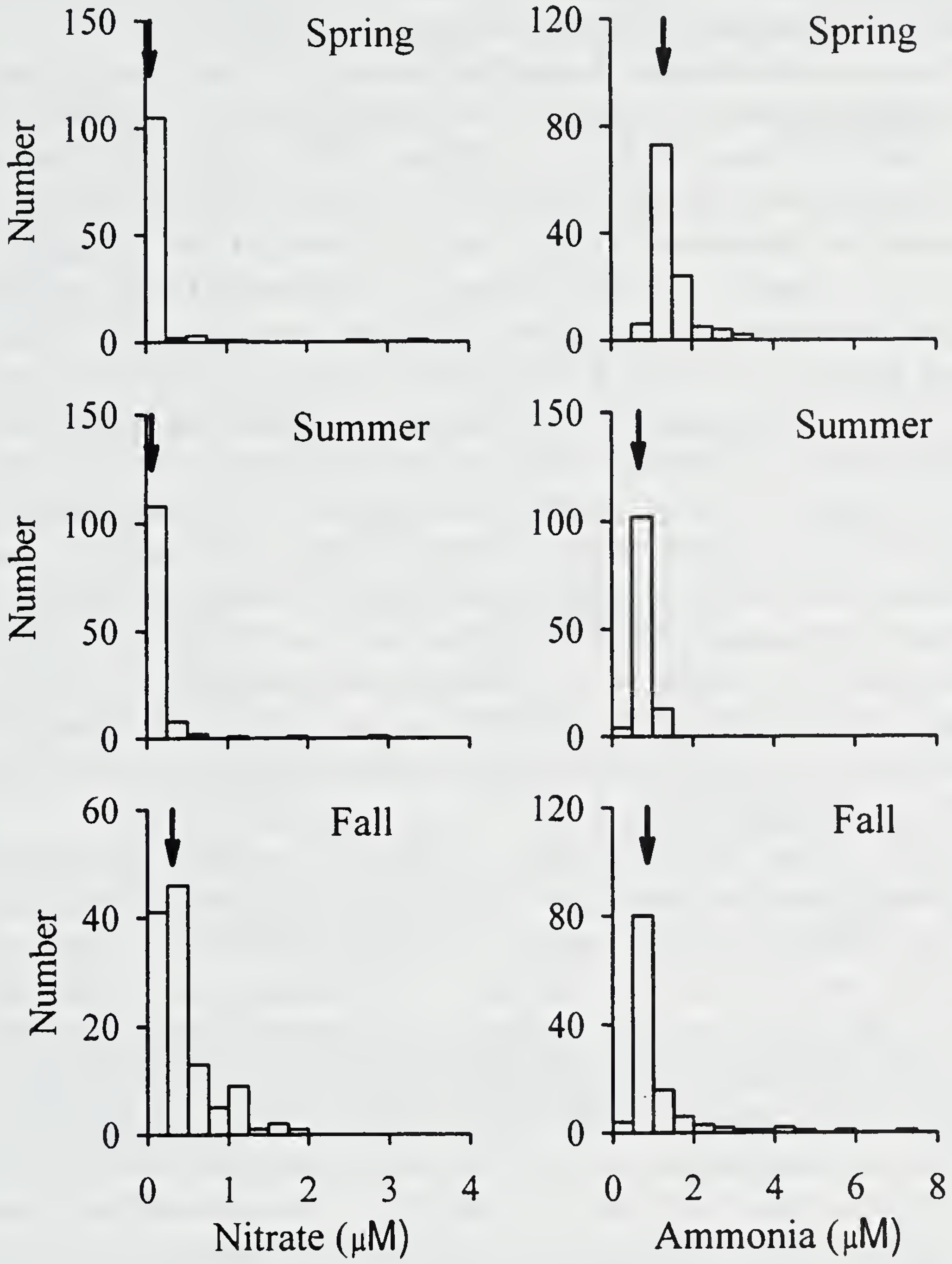

Fig 4 Seasonal distribution of nitrate and ammonia concentrations in the 0-15 m layer of the Bras d'Or Lakes, in 1996 (Strain *et al.*, 2001). Median values are shown by arrows.

Surface nitrate+nitrite (subsequently referred to as nitrate) levels were very low throughout the Lakes in the spring (Fig 4). Ninety-eight of 114 measurements were less than the detection limit of 0.14 µM. Only 2 samples had concentrations greater than 2 µM: a station in St. Patrick's Channel near Nyanza Bay and a station in Herring Cove at the head of Baddeck Bay (the latter site is a very small embayment, 30 m deep, isolated from the rest of Baddeck Bay by a sill with a depth of less than 10 m; see Fig 3). These very low surface concentrations of nitrate are typical of conditions in inlets on the Atlantic coast of Nova Scotia after the growth of phytoplankton during the spring bloom has converted all the available oxidized nitrogen to organic nitrogen or ammonia (Keizer *et al.*, 1996). The very low nitrate concentrations typically persist through the summer. In the summer survey of 1996, 91 out 121 nitrate measurements in the Lakes from the top 15 m were below the detection limit. By the fall survey, only 22 of 119 nitrate measurements were below detection limit; 30 samples had levels greater than 0.5 µM, indicating that nitrate was being added to the surface layer faster than it was being consumed by production. The deepening of the surface mixed layer by fall winds is one mechanism that would contribute to the higher surface nitrate concentrations. Earlier studies (Geen and Hargrave, 1966; Young, 1976) also reported low concentrations of nitrate in the late spring and summer.

Surface ammonia concentrations in the spring were higher than those of the oxidized nitrogen, with a median value of 1.3 µM (Fig 4). This is typical of behaviour for inlets on the Atlantic coast of Nova Scotia (e.g. Strain, 2002), in which the dominant inorganic form of nitrogen after the spring bloom is ammonia. By July (Fig 4) the median ammonia concentration decreased to 0.67 µM, as demand for inorganic nitrogen continued to exceed its supply. In the fall survey, most ammonia concentrations were still less than 1 µM, but there were a number of higher values as well. All samples in Denys Basin were above 4 µM, with a maximum value of 7.2. Higher than median values were also found at the west end of Whycocomagh Bay, the Washabuck River, Nyanza Bay, and in the cove behind Seal Island in the Great Bras d'Or Channel (Fig 3). Since these higher ammonia levels were found in places with restricted circulation, they are probably due to organic matter decomposition in underlying waters and sediments. Land sources or direct sewage inputs might be another possibility, but there are no indications of ammonia levels this high in the rivers flowing into the Lakes, in either the data reported by Dalziel *et al.* (1998) or measurements made on streams flowing into Denys Basin by Strain *et al.* (2001) in the spring and fall of 1997. The ammonia levels reported by Geen and Hargrave (1966) are very similar to those from Strain *et al.* (2001), ranging from 2 to 3 µM.

In sharp contrast to nitrate, all of the spring dissolved phosphate concentrations are greater than the phosphate detection limit (0.038 µM), with a median value of 0.20 µM (Fig 5). Even using the sum of the median concentrations for nitrate, nitrite and ammonia (1.36 µM), the N:P ratio is only 6.8. The phosphate concentrations are clearly in excess of the total inorganic nitrogen available for phytoplankton growth. Based on the NOAA National Estuarine Eutrophication program definitions of low, medium and high nutrient concentration (Bricker *et al.*, 1999), total nitrogen concentrations fell into the low category for 446 of 450 surface samples (medium concentrations were found for 4 samples from Dena's Pond (Fig 3), Denys Basin and the southern end of St. Peter's Inlet), while ~10% of surface phosphate concentrations were in the medium range with a single sample (Dena's Pond) in the high range. This is further evidence that primary production in the Lakes is nitrogen limited. Surface layer phosphate concentrations observed in the summer and fall surveys are very similar to those seen in the spring survey. Phosphate levels determined by Geen and Hargrave (1966), 0.1 to 0.2 µM, are consistent with the more recent observations.

Like nitrate, the spring distribution of silicate is skewed to very low values, with 70 out of 114 measurements less than 1.0 µM in the spring (24 were at or below the detection limit of 0.19 µM; Fig 5). However, there are a number of high silicate concentrations in samples from the top of the surface layer (depth = 1 m). These high values are all found in or near Whycocomagh Bay, St. Patrick's Channel, Baddeck Bay and Denys Basin. This pattern is consistent with the presence of high silicate levels in freshwaters flowing into these parts of the Lakes. Dalziel *et al.* (1998) found high concentrations in the Middle River (mean = 41 µM), Baddeck River (73 µM), both of which flow into Nyanza Bay, and River Denys (42 µM), which flows into Denys Basin.

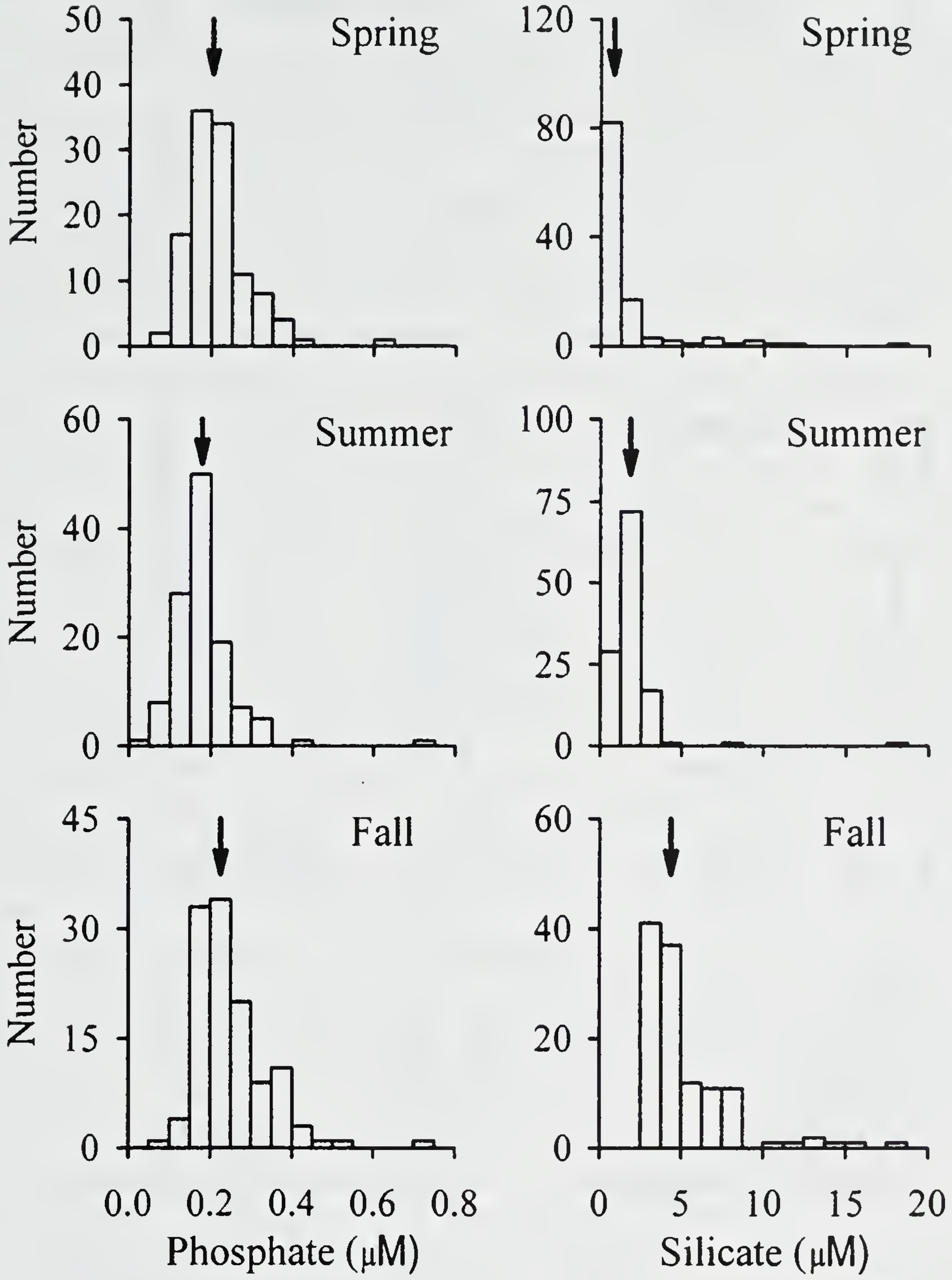

Fig 5 Seasonal distribution of phosphate and silicate concentrations in the 0-15 m layer of the Bras d'Or Lakes, in 1996 (Strain *et al.*, 2001). Median values are shown by arrows.

By summer, the median silicate value had increased from 0.81 to 1.82 μM. Approximately half of the silicate values fell between 1 and 2 μM; no measurements were below the detection limit. There were fewer high levels of silicate: in the spring, 10 samples had concentrations greater than 5 μM; in the summer, only one sample contained more than 5 μM. The summer concentrations reflect the balance between silicate delivery by the rivers (which may have been lower due to a drought in early summer, 1996) and diatom production. By the fall, the median value of silicate had increased even more, to 4.4 μM. Similar to the spring survey, high values were found in St. Patrick's Channel, Whycocomagh Bay, Denys Basin (all samples in Denys Basin were > 10 μM), and at a single station at the northeast end of East Bay. At this time of year, silicate supply exceeded the demand from diatom growth.

The chlorophyll *a* concentrations were very low throughout the Lakes during the spring of 1996: 95 out of 106 samples had chlorophyll *a* levels at or below 0.5 μg L^{-1} (Fig 6). No sign of an active bloom was indicated by these samples. By summer,

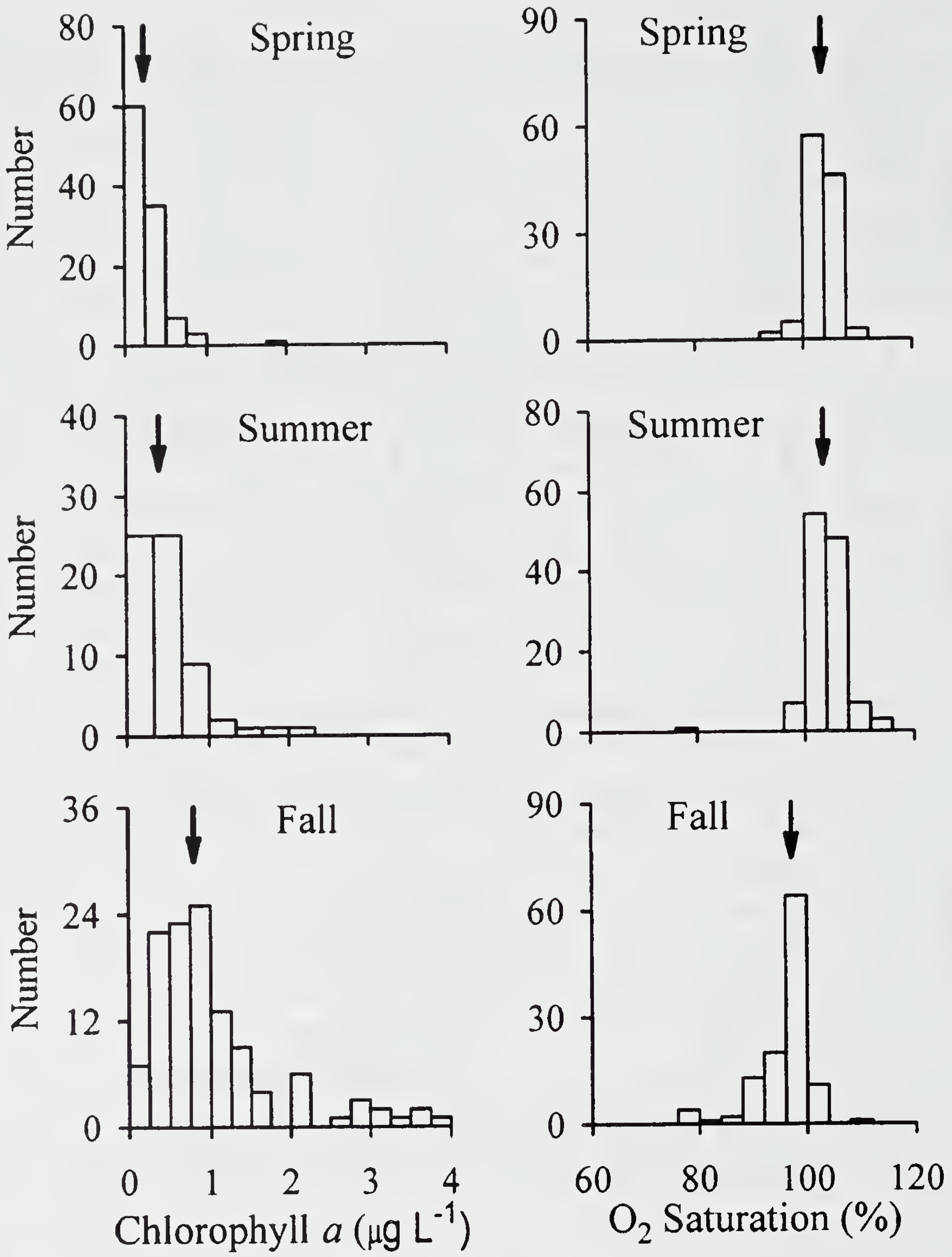

Fig 6 Distribution of chlorophyll *a* and dissolved O_2 saturation in the 0-15 m layer of the Bras d'Or Lakes, in 1996 (Strain *et al.*, 2001). Median values are shown by arrows.

the median chlorophyll *a* level had increased marginally, from 0.24 to 0.40 µg L^{-1}, but overall phytoplankton biomass remained very low. The chlorophyll and phaeophytin (a degradation product of chlorophyll, which was also present in very low concentrations) concentrations for the fall survey show that some additional algal growth had occurred: the median concentration for chlorophyll was 0.80 µg L^{-1}. The highest chlorophyll values (> 2 µg L^{-1}) were found in Whycocomagh Bay, St. Patrick's Channel, Denys Basin, St. Peter's Inlet and at a single station at the southeast end of St. Andrew's Channel. Geen and Hargrave (1966) measured similar chlorophyll concentrations in waters of the open Lakes (1 to 3 µg L^{-1}), and cautioned that inshore estimates of chlorophyll were often biased by the chlorophyll present in organic detritus. Detrital chlorophyll might also explain higher near-bottom concentrations of chlorophyll seen in nearshore samples by Young (1973a). Young's data from more open areas of the Lakes (0.4 - 1.9 µg L^{-1}) are similar to the data from the other studies.

As expected, the surface layer oxygen concentrations were always close to saturation (Fig 6). The distribution observed by Strain *et al.* (2001) is narrow, with a median value of 104 % in the spring and summer surveys. The slight supersaturation could be due to production exceeding respiration in the surface layer, or to warming of the layer occurring faster than equilibration with the atmosphere. Dissolved oxygen concentrations were slightly lower on the fall survey, with a median value of 97 % saturation. This may be a further indication of decomposition processes, or it could be due to physical processes: the surface layer could have been cooling faster than air-sea exchange could re-establish equilibrium conditions.

The low spring concentrations of the inorganic nitrogen species in 1996, together with the very low values of chlorophyll and phaeophytin, suggest that a spring bloom had already occurred in the Lakes prior to these surveys. The generally low concentrations of silicate, despite the abundant silicate in some of the rivers feeding the Lakes, suggests that diatoms were a significant part of the bloom and were responsible for removing most of the silicate from the surface layer.

By the time of the fall survey in 1996 (Sept. 22-27), many of the distributions had changed from those observed in spring and summer. The changes in properties seen in the fall data are consistent with a modest bloom fuelled by an increase of nutrients in the surface layer. This re-supply was due to a combination of regeneration and vertical mixing caused by fall wind conditions and the reduction in stratification due to fall cooling. However, there is no such evidence for a bloom in the data for the other two fall surveys (1995 and 1997) reported by Strain *et al.* (2001), although the absence of pigment data for these other surveys makes this conclusion tentative. The nitrate and ammonia distributions in these two surveys were more similar to those observed on the spring and summer surveys in 1996 than the distribution in the fall of 1996. The more restricted spatial coverage of the 1995 and 1997 data should not affect this conclusion, since both of these surveys covered some of the areas with the highest chlorophyll concentrations found in 1996. It is not known whether the evidence of a bloom in late September 1996 and the apparent absence of a fall bloom in 1995 and 1997 indicate that blooms may occur in some years and not others, or simply that the timing of the bloom was different in different years (the three fall surveys were conducted on almost identical dates). Regardless, these observations further illustrate the variations in seasonal cycles that occur between different years.

Nutrient Distributions in Deep Waters. Nutrient concentrations in deeper waters also influence the potential productivity of marine ecosystems. Dead organisms and other organic detritus sink into the deep water, where they decompose, either in the water or in the bottom sediments, and release inorganic nutrients back into the water column. Physical mixing processes, such as diffusion and upwelling, can then resupply the photic zone (the layer in which light levels are high enough to support photosynthesis) with the nutrients needed for phytoplankton growth. In temperate latitudes, this resupply typically occurs in the fall and winter when cold temperatures and storm winds break down the stratification of the water column and mix regenerated nutrients from the deep water into the surface layer.

Fig 7 shows the nitrate levels observed in the 1996 surveys (Strain *et al.*, 2001) at stations representative of the deep basins in the Lakes. At Great Bras d'Or 1 (Fig 3), nitrate levels are very low and uniform throughout the water column in spring, summer and fall. These low levels are a reflection of the intense mixing that occurs in the northeastern section of the Great Bras d'Or Channel which prevents the accumulation of both organic detritus and regenerated nutrients. This behaviour contrasts to the southwestern end of the Channel (Great Bras d'Or 2), where concentrations of nitrate

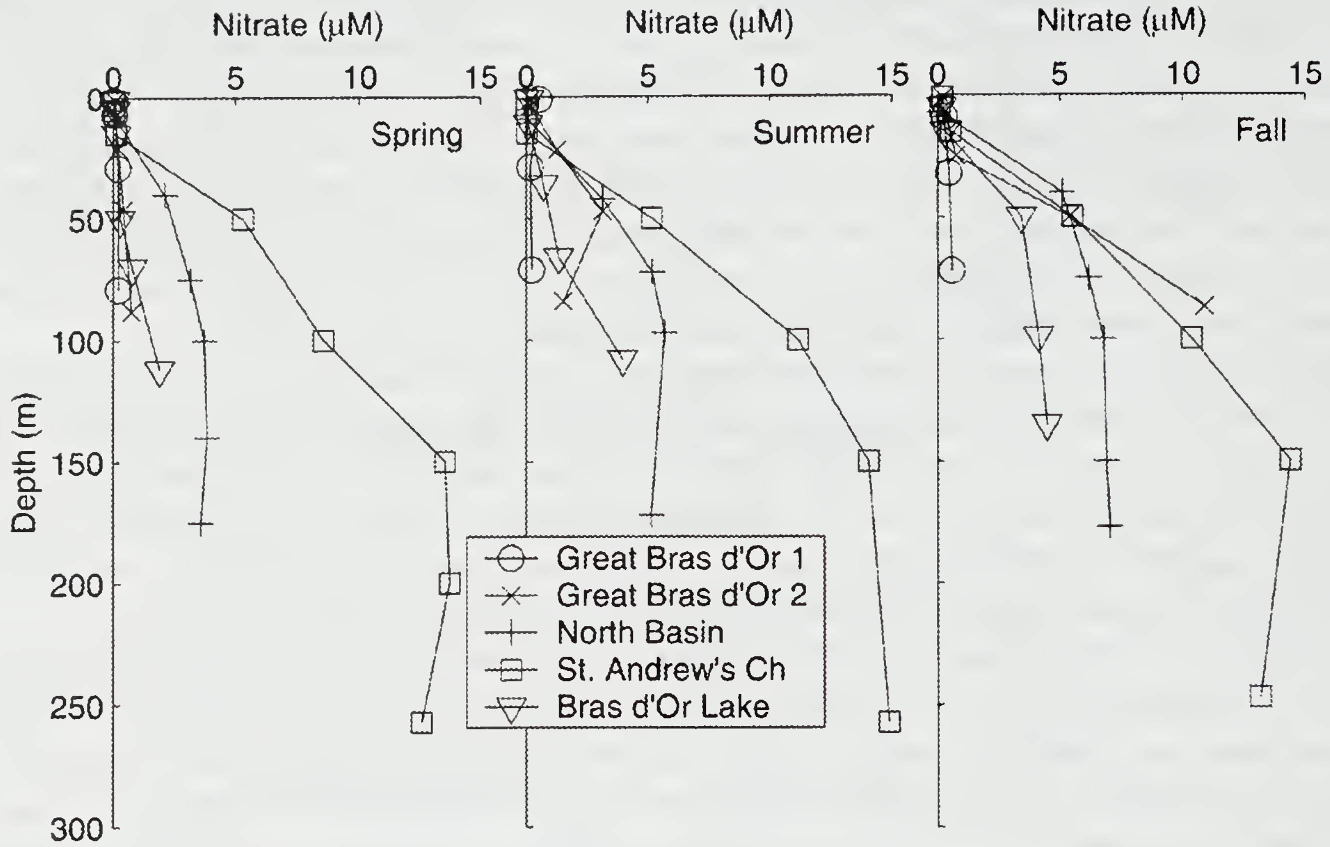

Fig 7 Nitrate at 5 deep stations in the Bras d'Or Lakes in 1996 (Strain *et al.*, 2001).

at depth increase from spring to fall, to levels that are higher than the concentrations in the inflowing water from Sydney Bight, illustrating the importance of the regeneration processes described above. Similar nitrate increases from spring to fall also occur in the deep waters of St. Andrew's Channel, North Basin, and Bras d'Or Lake (we will use Bras d'Or Lake, singular, to refer to the Lake basin south of Barra Strait). The concentrations of nitrate at similar depths in these 3 areas, however, are markedly different. Levels are highest, and vary the least from season to season, in St. Andrew's Channel. The high fall concentrations at the southwestern end of the Great Bras d'Or Channel suggest that some St. Andrew's Channel deep water may mix with water outside the channel. The lower concentrations found in the North Basin, however, show that this mixing does not reach the North Basin and may be quite limited.

Nitrate levels in Bras d'Or Lake south of Barra Strait are lower than the levels in both St. Andrew's Channel and the North Basin north of Barra Strait. Barra Strait, and the shallow sill north of the Strait (depths < 30 m), are effective barriers to nitrate supply from Sydney Bight or from the deep reservoir in St. Andrew's Channel. These concentration differences combined with estimates of vertical mixing (Gurbett and Petrie, 1995) suggest that the flux of nitrate into the surface layer is 5-10 times greater north of Barra Strait than in the Bras d'Or Lake. The lower availability of nitrogen in the Lakes south of Barra Strait probably makes the total production there significantly lower than north of Barra Strait.

The vertical profiles for phosphate (Fig 8) and silicate (Fig 9) are generally similar to those for nitrate, except for the previously noted differences in the surface layer. A significant difference between the silicate profiles and those for nitrate and phosphate is that the difference between silicate levels north and south of Barra Strait that were observed in spring and summer had disappeared by the fall. In addition, the contrast between the deep water concentrations inside the Lakes and those in the Sydney Bight input is greater for silicate than it is for nitrate or phosphate. These observations show

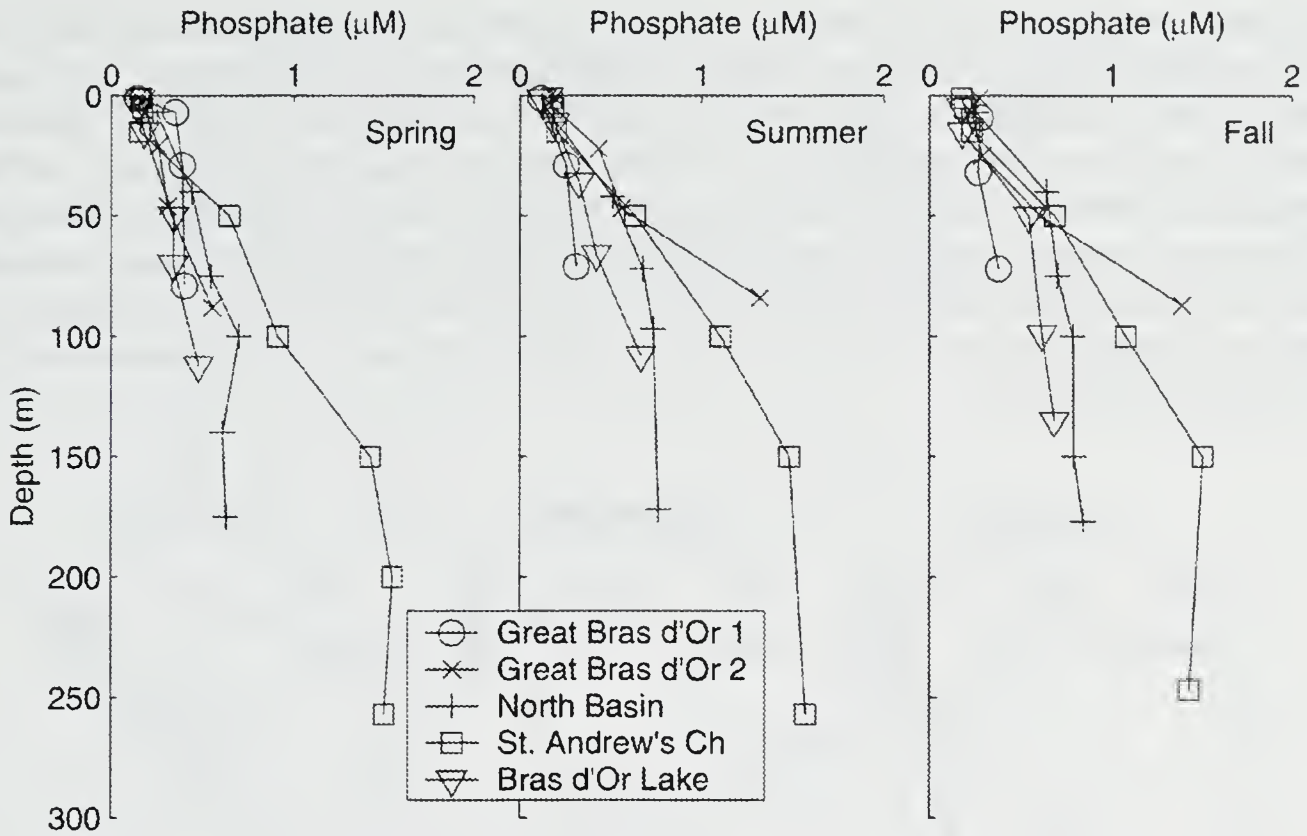

Fig 8 Phosphate at 5 deep stations in the Bras d'Or Lakes in 1996 (Strain *et al.*, 2001).

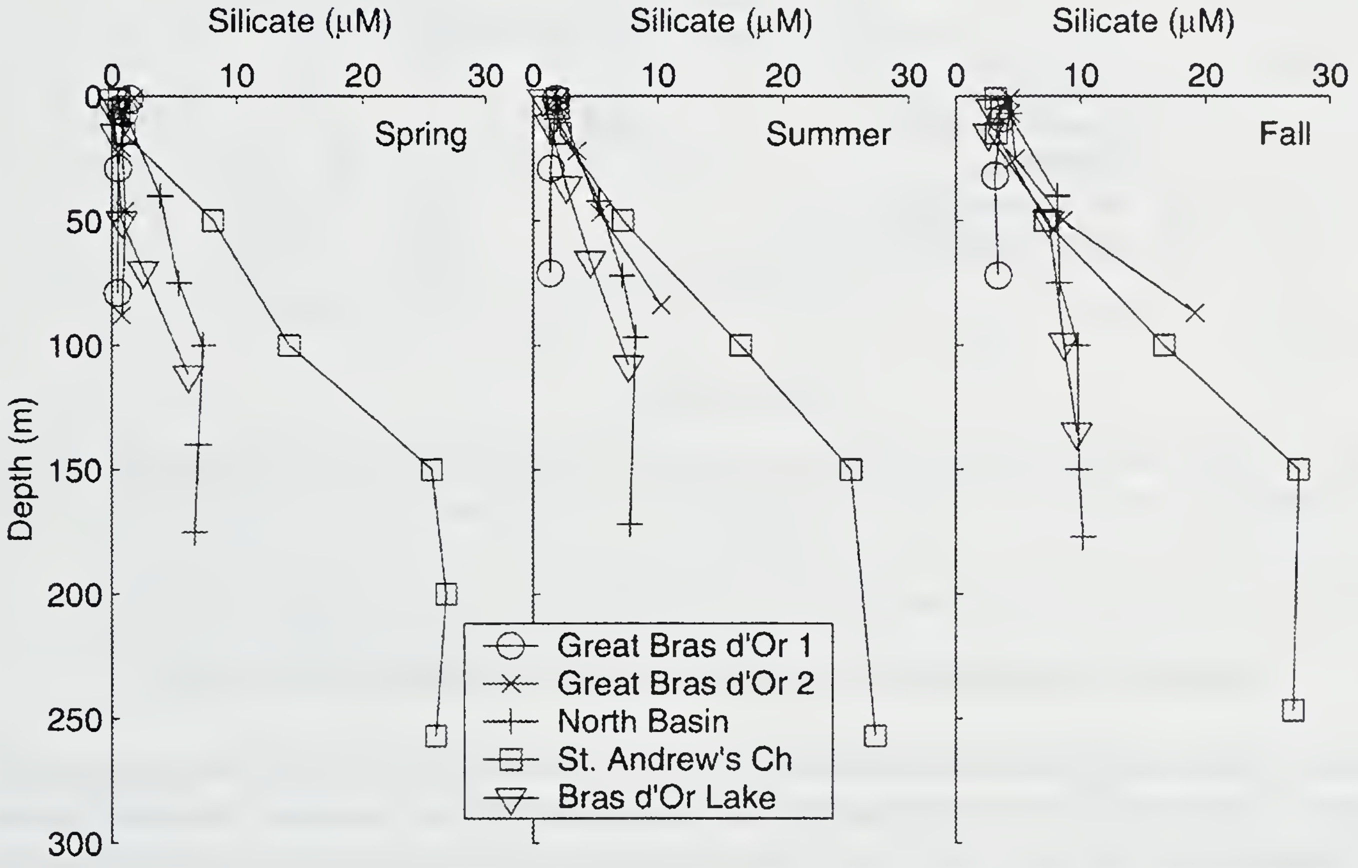

Fig 9 Silicate at 5 deep stations in the Bras d'Or Lakes in 1996 (Strain *et al.*, 2001).

that internal sources and internal recycling processes are more important, and advective transport is less important, for silicate than for nitrate or phosphate.

Dissolved oxygen saturation levels (Fig 10) are almost mirror images of the nitrate profiles (Fig 7); this is expected for the aerobic decomposition of organic matter which consumes oxygen in a constant proportion to the nitrate produced. Dissolved oxygen levels decreased in the southwestern end of the Great Bras d'Or Channel, the North Basin and Bras d'Or Lake from spring to fall, as the decomposition proceeded. However, the dissolved oxygen levels in the deepest samples from St. Andrew's Channel were very consistent, at 57, 55 and 55 % for the spring, summer and fall, respectively. These constant values suggest that the oxygen consumed by regeneration and the oxygen supplied by advection of new water into the basin were approximately in balance during this period. Over longer times, however, the oxygen levels in St. Andrew's Channel do vary: in July, 1974 the oxygen saturation in the deep water was 78 % (Krauel, 1975).

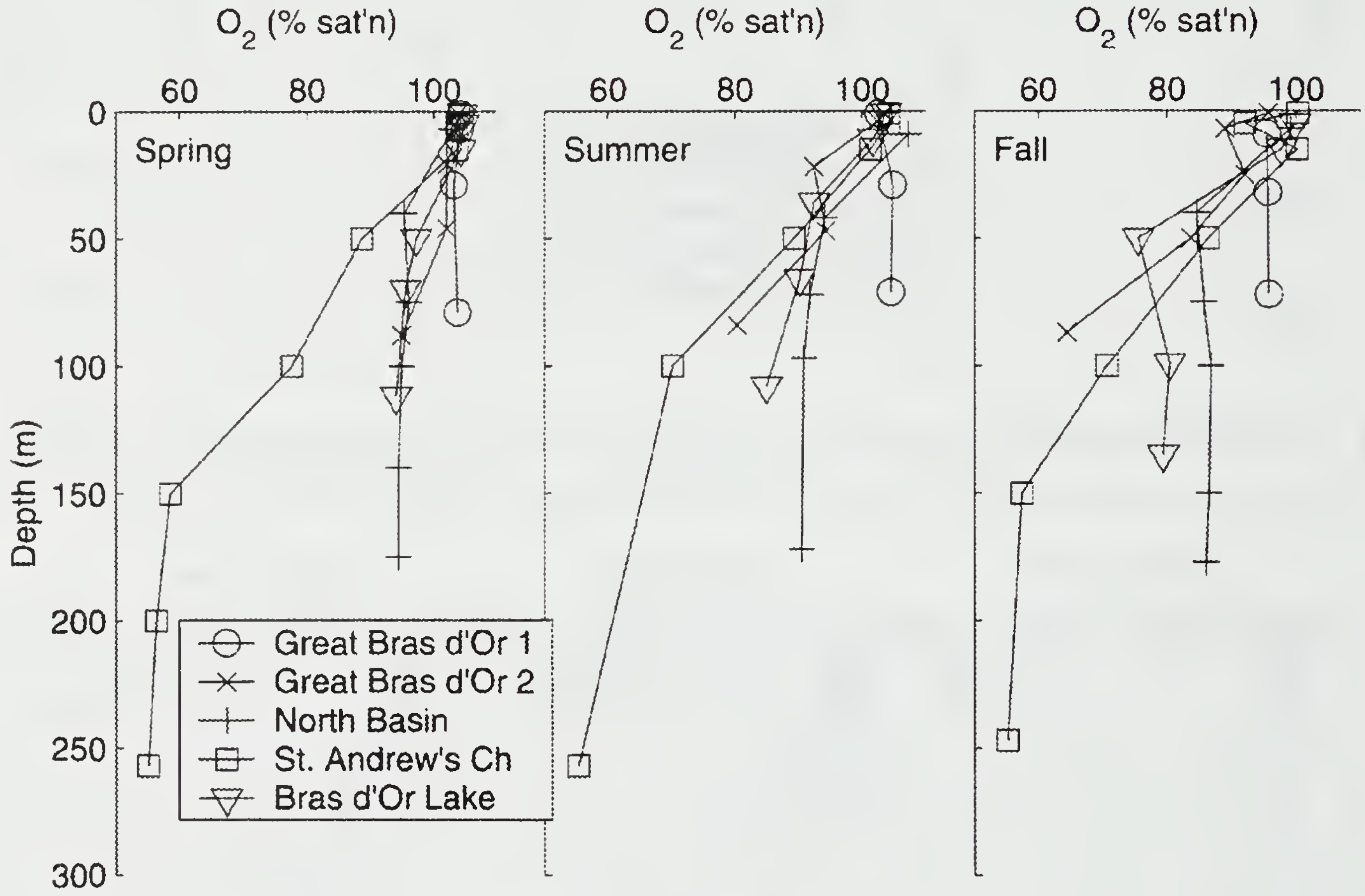

Fig 10 Oxygen saturation at 5 stations in the Bras d'Or Lakes in 1996 (Strain *et al.*, 2001).

Nutrient Conditions in Embayments of the Bras d'Or Lakes

So far the discussion has focussed on nutrient dynamics in the Lakes as a whole, or the major basins within the Lakes. However, the degree of isolation of many of the smaller basins and inlets around the Lakes can lead to conditions that are very different than the average conditions in the Lakes.

Whycocomagh Bay. Fig 11 shows the distribution of nutrients and dissolved oxygen in Whycocomagh Bay for the fall, 1995, and illustrates a number of the processes that occur in many of the smaller embayments in the Lake system. Whycocomagh Bay contains two deep basins separated by a broad, shallow sill (~7 m deep): the western one is narrow and steep-sided with a maximum depth of ~48 m; the eastern one is comparatively wide and gently sloped with a maximum depth of ~38 m. Whycocomagh Bay as a whole has a very restricted connection to the rest of the Lakes through Little Narrows, which is only 100 m wide and ~12 m deep. Gurbutt *et al.* (1993) estimated that the flushing time for the deep waters of the two basins in

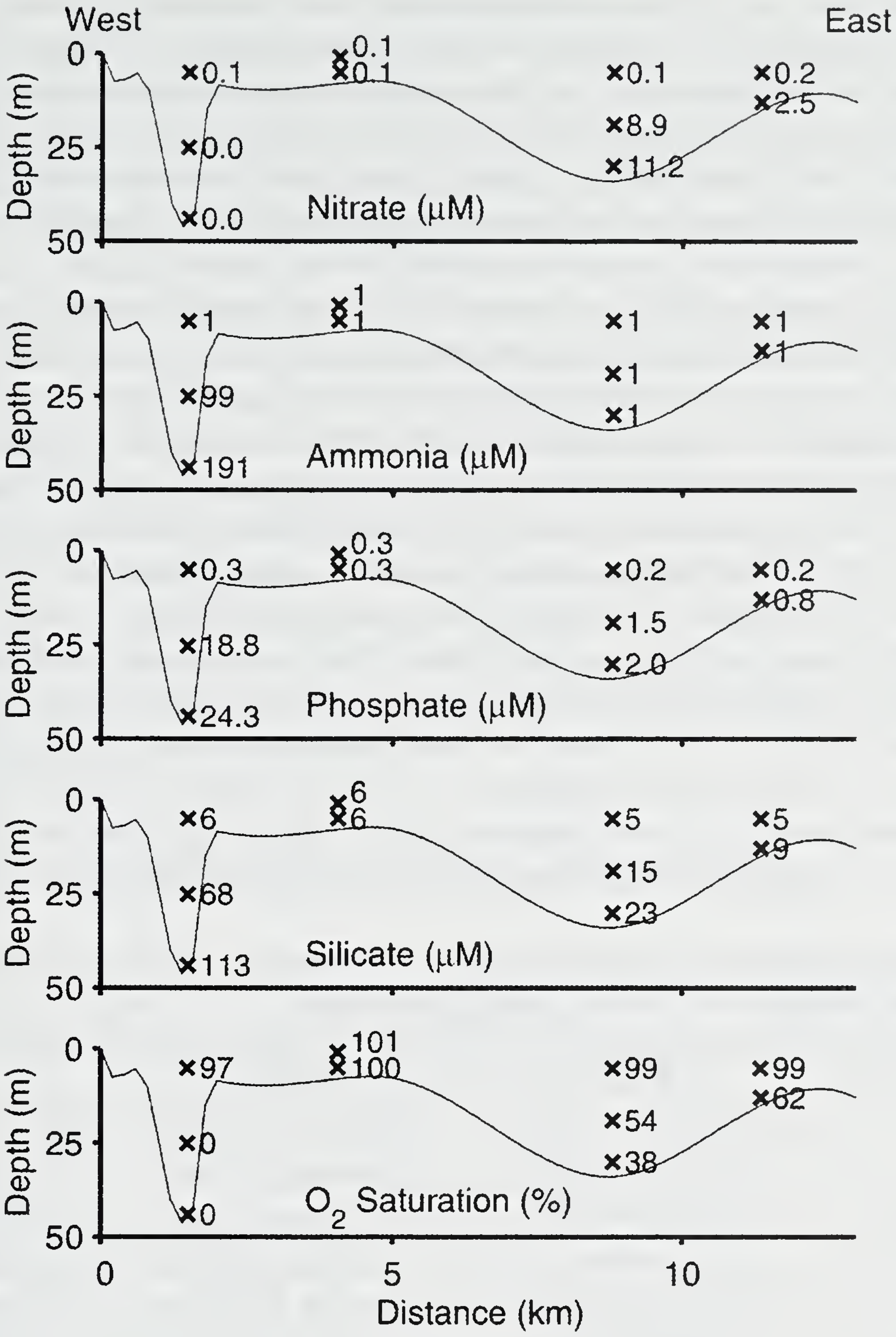

Fig 11 Cross-section of nutrient concentrations and % oxygen saturation in Whycocomagh Bay in the fall of 1995 (Strain *et al.*, 2001). Sample locations are indicated by X's and values for each measurement are given. The depth of the Bay is shown as a continuous line.

Whycocomagh Bay is approximately 2 y. But the nutrient and oxygen data show that the regeneration processes in the two basins are quite different. In the bottom water of the eastern basin, the dissolved oxygen levels were relatively high (38 % saturation), and significantly elevated levels of nitrate (11.2 μM), phosphate (2.0 μM), and silicate (23 μM) were observed. The presence of residual oxygen, high levels of nitrate, and low levels of ammonia all indicate that the organic matter decomposition had occurred aerobically. In the western basin, in contrast, there was no nitrate or oxygen in the deep water, and the ammonia concentration was 191 μM near the bottom. Profiles obtained with a profiling oxygen sensor from 1995-1997 (Strain, unpublished data) show that dissolved oxygen consistently falls to zero at depths between 10 and 15 m in the western basin. Similar results were reported by Krauel (1975) for July 1974, when dissolved oxygen was at 47 % saturation at 15 m, and anoxic by 25 m. Furthermore, sulfide, which does not normally co-exist with oxygen, has been measured in the deep water of the western basin at concentrations of 30-60 µM (Strain *et al.*, 2001). All of these observations indicate that anaerobic decomposition of organic matter (i.e. decomposition in the absence of oxygen) occurs in the western basin. The very high values of phosphate (24 µM) and silicate (113 µM) show that more decomposition products have accumulated in the western basin than in the eastern basin. The most likely reason for the differences between the two basins is that the flushing time of the western basin is significantly longer than that of the eastern basin.

Denys Basin. Denys Basin is a small (~25 km^2) basin of some economic and cultural significance because of its oyster population and the local harvesting of oyster spat. In recent years some of the shellfish areas in Denys Basin have been closed because of unacceptable faecal coliform levels. Possible sources of the contamination are inadequate treatment of domestic sewage and inputs from farms in the River Denys drainage basin. Although there is no sill separating Denys Basin from the rest of the Lakes, the only connection to the Lakes is a narrow winding channel ~7 km long. This isolation raises the possibility that the basin may accumulate inputs; however the average nutrient, dissolved oxygen, and chlorophyll concentrations (Table II) are very similar to those in other areas of the Lakes (Fig 4-6). Denys Basin did show some small differences from the rest of the Lakes. Ammonia levels in the fall were higher in 1996 than in other parts of the Lakes, reaching a maximum value of 7.2 µM, despite the fact that the maximum ammonia level observed in the inflowing rivers in falls from 1993-1997 was only 1.0 µM (Dalziel *et al.*, 1998; Strain *et al.*, 2001). Two observations of oxygen levels between 75 and 80 % saturation were made at 5 m depths in the fall of 1996. These values are not extreme, but even this reduction in O_2 is unusual at such a shallow depth for exposed waters. Even anoxic conditions can occur at depths as shallow as 5 m in protected barachois ponds (Smith and Rushton, 1964).

Table II Concentrations of chlorophyll, nutrients, and dissolved O_2 in Denys Basin (data from Strain *et al.*, 2001). Mean ± 1 σ(n)

	Spring	Summer	Fall
Nitrate (µM)	0.07 ± 0.14 (12)	0.06 ± 0.04 (6)	0.42 ± 0.60 (20)
Ammonia (µM)	0.97 ± 0.44 (11)	0.68 ± 0.10 (6)	2.08 ± 2.09 (20)
O_2 saturation (%)	102.2 ± 1.9 (6)	108.2 ± 4.7 (6)	92.9 ± 6.9 (16)
Phosphate (µM)	0.15 ± 0.06 (12)	0.18 ± 0.07 (6)	0.23 ± 0.09 (20)
Silicate (µM)	3.94 ± 2.74 (12)	1.44 ± 0.31 (6)	6.19 ± 4.61 (20)
Chlorophyll (µg L^{-1})	0.45 ± 0.28 (6)	0.40 ± 0.08 (5)	1.48 ± 1.30 (6)

Other Small Inlets. Growth and decomposition processes have different impacts in the various small embayments around the Bras d'Or Lakes. Fig 12 shows nitrate, dissolved O_2, ammonia and phosphate profiles for 5 such sites (Fig 3). Herring Cove is a small bay (about ~300 m across) separated from the rest of Baddeck Bay by a sill less than 10 m deep. The Washabuck River site is in a small bay connected to St. Patrick's Channel by a very narrow channel (~20 m wide) over a shallow sill (<5 m deep). St. Peter's 1, another silled basin, is adjacent to the town of St. Peters at the south end of St. Peter's Inlet. It has been the site of finfish aquaculture. St. Peter's 2, also in St. Peter's Inlet, is approximately 4 km from the open Lake, but is not separated from it by a sill. Dena's Pond is a small bay (~0.5 x 1.5 km) that has supported rainbow trout aquaculture for many years and is almost totally isolated from the rest of the Lakes: at its narrowest, the mouth of the pond is approximately 150 m wide, and less than 1 m deep; the maximum depth in the pond is ~25 m. Aerobic decomposition apparently dominates at these sites, given that nitrate concentrations in the bottom water generally increase from spring to fall. The highest nitrate values occur in Herring Cove, Dena's Pond and St. Peter's 1, the 3 bays with significant sills separating them from the open Lakes. Strain and Yeats (1999) showed that the presence/absence of sills is the dominant factor that determines the sensitivity of Nova Scotia inlets to eutrophication (i.e. the build-up of nutrients). Herring Cove also shows a number of differences from the other sites. High levels of ammonia are present in the deep water at all times of year, despite significant levels of dissolved O_2 in spring and summer. It is possible that some anaerobic decomposition also occurs in Herring Cove, especially since dissolved O_2 levels are close to zero in the fall. But another possibility is that there are local inputs of ammonia to Herring Cove. Herring Cove is also one of the few sites in the Lakes that shows high surface concentrations of nitrate in spring and summer, perhaps due to local sources of nitrate. The high summer nitrate level at the surface, together with the low phosphate value, may indicate that primary production in Herring Cove is briefly phosphate limited in the summer. In contrast, Dena's Pond shows very high levels of phosphate, which might be due to extreme isolation of this Pond from the Lakes and the accumulation of wastes from aquaculture operations and other sources.

Organic Contaminants And Heavy Metals

Very few measurements have been made of organic contaminants in the Bras d'Or Lakes. Bailey and Howell (1983) reported 0.104 µg/g of total PAHs in sediment and 0.006 µg/L in water at a station in St. Patrick's Channel off Kidston Island. The Willis (1999) study included measurement of individual PCB and PAH compounds in sediments from 5 sites in the Lakes (Whycocomagh Bay, Baddeck Bay, East Bay, Denys Basin and Nyanza Bay). None of the PCB compounds were present at concentrations above the detection limit of 0.2 ng/g, and none of the PAHs were above the detection limit of 8 ng/g, except for 8.5 ng/g of fluoranthene and 9.3 ng/g of benzo(b)fluoranthene in the sample from Baddeck Bay. None of these concentrations approach any of the Canadian Council of Ministers of the Environment sediment or water quality guidelines for the protection of aquatic life (CCME, 1999).

Young (1973b, c) and Creamer *et al.* (1973) reported concentrations of 9 metals in oysters, mussels and sediments from a number of inlets and bays around the periphery of the Bras d'Or Lakes. Chou *et al.* (1999) have reported concentrations of 21 metals from liver and kidney tissues of winter flounder and sediments from Whycocomagh Bay, Baddeck Bay, East Bay, Denys Basin and Nyanza Bay. Average concentrations determined in these 2 studies conducted 25 years apart and using very different techniques are listed in Table III. The spatial variability that was found during the investigations is discussed in the original papers, but no consistent patterns that showed elevated levels of several metals in any one area were seen. With the exception of the Cd concentration reported by Creamer *et al.* (1973), all the average sediment concentrations are below Probable Effects Levels quoted in the CCME (1999) quality guidelines. Cd levels measured in 1972 should probably be considered unreliable because of limitations of the analytical techniques that were generally used for Cd at that time. The more recent results (Chou *et al.*, 1999) show Cd levels are well below the guideline. Biota levels are also low except for the Zn value reported for oysters. Oysters are known to bioaccumulate Zn, even in the absence of elevated environmental concentrations, and the levels found in the Lakes are not high compared to those found elsewhere (Young, 1976).

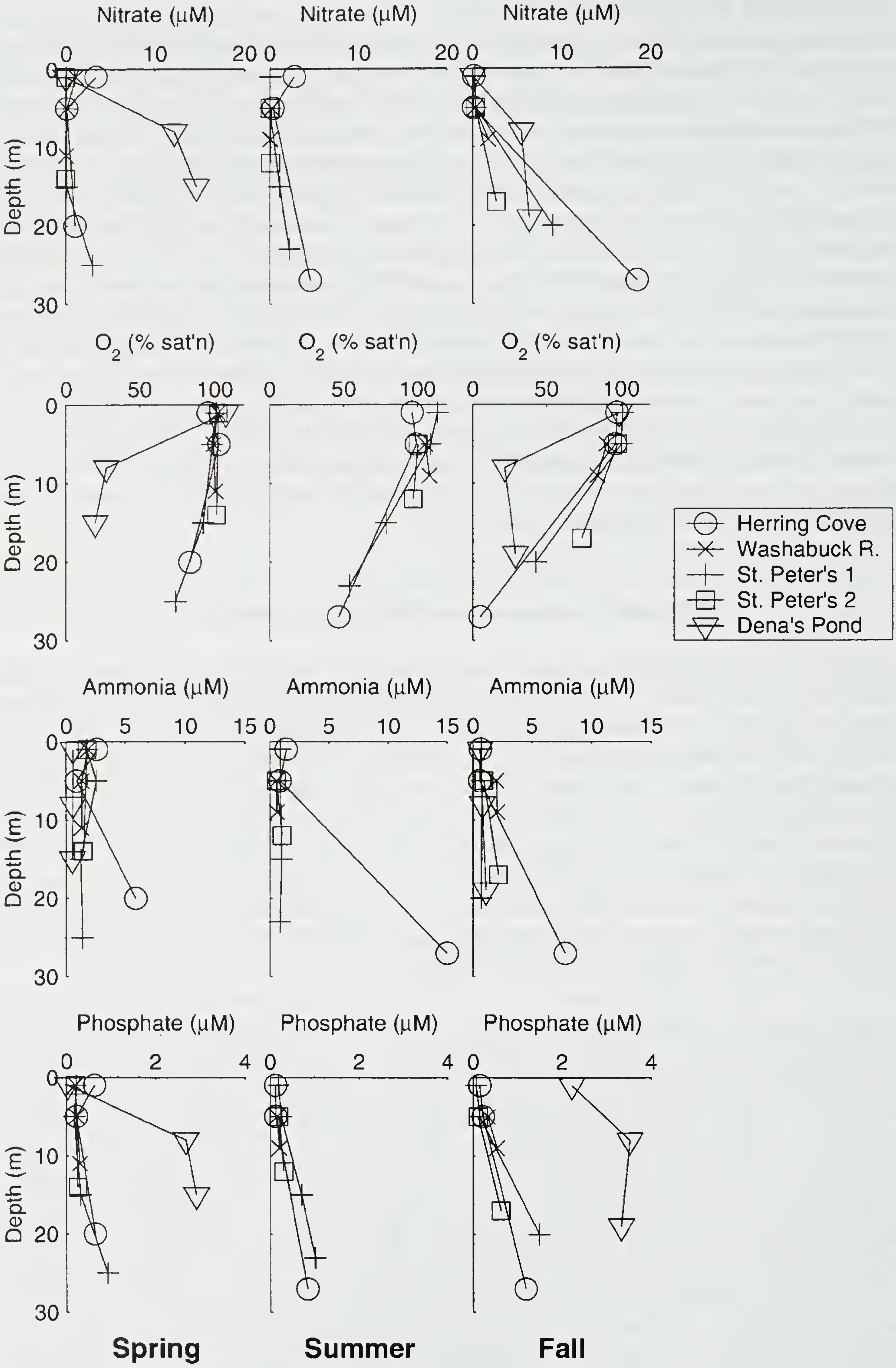

Fig 12 Nitrate, ammonia, and phosphate (µM) and % oxygen saturation in 5 embayments around the Bras d'Or Lakes (Strain *et al.*, 2001). See Fig 3 for locations.

Table III Average metal levels in biota and sediments from the Bras d'Or Lakes (biota, µg/g wet, and sediments µg/g dry).

Metal	Oyster[1]	Mussel[2]	Sediment[3]	Flounder kidney[4]	Flounder liver[4]	Sediment[4]
Al	19.7	15				
Ag					0.36	0.069
As				1.27	13.6	6.37
Cd	1.28	0.6	18	0.13	0.66	0.15
Co				0.16	0.41	5.62
Cr	0.086	0.18	79	0.62	0.67	31.9
Cu	20.9	2.0	58	0.77	11.1	10.5
Fe	43.7	35	27000			
Hg	0.037					
Li				0.09	0.06	32.6
Mn	8.3	11	720	1.07	1.71	136
Mo				0.07	0.17	1.71
Ni				0.78	0.72	72.6
Pb	0.90	2.0	95	0.05	0.07	5.42
Se				2.92	2.46	4.61
Sr	1.36	1.5		0.86	0.51	13.7
Ti				0.34	0.29	1445
Tl				0.003	0.003	0.27
U				0.022	0.015	2.12
V				0.97	0.99	51.4
Zn	931	26	97	30.9	41.6	47.0

[1] Young, 1973b

[2] Young, 1973c

[3] Creamer et al., 1973

[4] Chou et al., 1999

Table IV Comparison of dissolved metal concentrations in the Bras d'Or Lakes waters with those in other areas (mean ± standard deviation).

	Bras d'Or[1] 13 samples	Halifax Hbr[2] 63 samples	Pictou Hbr[3] 19 samples	Ship Hbr[4] 42 samples	SydneyHbr[4] 32 samples
Cd (µg L^{-1})	0.021±0.010	0.036±0.011	0.033±0.010	0.022±0.006	0.023±0.006
Cu (µg L^{-1})	0.29±0.03	0.42±0.15	0.60±0.24	0.22±0.04	0.46±0.11
Fe (µg L^{-1})	1.2±0.9	2.3±1.2	6.9±4.4	2.7±1.6	3.3±3.3
Mn (µg L^{-1})	1.5±1.1	1.8±1.0	2.7±1.8	2.9±1.8	7.1±3.9
Ni (µg L^{-1})	0.22±0.04	0.47±0.17	0.36±0.06	0.30±0.11	0.43±0.19
Pb (µg L^{-1})	0.011±0.008	0.057±0.064	0.046±0.023	0.015±0.010	0.028±0.013
Zn (µg L^{-1})	0.83±0.69	3.1±1.9	1.2±0.6	1.0±0.9	1.0±1.0
Hg (ng L^{-1})	0.80±0.19	1.01±0.67			

[1] Survey 95908, Strain et al., 2001.

[2] Dalziel et al, 1991.

[3] Dalziel et al., 1993.

[4] Yeats, unpublished data.

Early studies of dissolved metal concentrations in Lake waters (Young *et al.*, 1959; Young, 1976) are of little value because of limitations of the analytical techniques. More recently, a small number of dissolved metal concentrations in the Bras d'Or Lakes were measured on two surveys (Strain *et al.*, 2001). The first survey (BIO cruise 95908, Sept 1995) showed that concentrations at 11 stations throughout the Lakes (Table IV) were consistently lower than those found in the more industrialized Halifax, Pictou and Sydney Harbours (Dalziel *et al.*, 1991, 1993; and Yeats, unpublished data) and more comparable to those in relatively pristine Ship Harbour (Yeats, unpublished data) despite the fact that salinities in the Lakes are only 20-25. We would expect lower salinities to result in higher concentrations because freshwater concentrations of these metals are generally higher than those in seawater. Metal concentrations in the Cape Breton rivers, however, are generally relatively low (Dalziel *et al.*, 1998).

In the second survey, only near bottom samples from basins with restricted water exchange were collected. Several of these had depleted oxygen concentrations (one was anaerobic). Dissolved iron and manganese concentrations were much higher (by a factor of approximately 500) in these oxygen depleted waters than elsewhere in the Lakes. Cd, Ni, Pb and Zn concentrations were unaffected and Cu was higher in only one sample (Dena's Pond). These measurements were part of a larger dataset used in a study of eutrophic bottom waters in Nova Scotia inlets (Strain and Yeats, 1999) that showed that Fe and Mn concentrations, but not those of Cd, Cu, Ni, Pb or Zn, are affected by the reduced oxygen concentrations that accompany eutrophication. The elevated concentrations of Fe and Mn result from their natural redox chemistry (the lower oxidation state compounds of Fe and Mn are more soluble than the higher oxidation state ones), not from pollution.

Metal Inputs. The main source of heavy metals in the Lakes is inflowing water from Sydney Bight through the Great Bras d'Or Channel. This source is greater by approximately an order of magnitude than inputs from either atmospheric precipitation or river runoff. Calculated inputs from rivers, offshore exchange, precipitation and sewage are shown in Table V. River inputs are based on the concentration data in Dalziel *et al.* (1998), the offshore inputs on data for metal concentrations in Sydney Bight (Yeats *et al.*, 1998 and unpublished data from surveys of Sydney Harbour), and precipitation and sewage concentrations from generic assessments of concentrations in these two inputs (Bond and Straub, 1974; GESAMP, 1989; Petrie and Yeats, 1990; MacNeil and Hurlbut, 2000). There were enough data to generate seasonal values only for the river inputs, all the rest are annual averages. Water transports are the same as those used for calculating nutrient inputs. The dominance of the Sydney Bight inputs in Table V is somewhat artificial because the exchange through the Great Bras d'Or Channel will have the greatest impact on the parts of the Lake closest to it, while inputs from precipitation, rivers and sewage will be distributed throughout the Lakes.

Table V Inputs of metals to the Bras d'Or Lakes.

	Units	Precip	Rivers Spring	Rivers Summer	Rivers Fall	Sewage	Sydney Bight
SPM	mg m^{-2} d^{-1}	11.0	12.3	4.7	8.9	0.67	145
Al	µg m^{-2} d^{-1}	880	1100	240	840	0.58	12600
As	µg m^{-2} d^{-1}	0.18	2.5	2.3	2.4	0.20	105
Cd	ng m^{-2} d^{-1}	102	113	97	99	0.003	2600
Cu	µg m^{-2} d^{-1}	1.10	5.2	7.1	3.8	0.20	36
Fe	µg m^{-2} d^{-1}	380	1100	310	980	3.6	7800
Mn	µg m^{-2} d^{-1}	1.21	73	62	140	1.05	350
Ni	µg m^{-2} d^{-1}	0.79	3.2	2.9	3.6	0.036	40
Pb	ng m^{-2} d^{-1}	2800	1300	560	920	0.024	9500
Zn	µg m^{-2} d^{-1}	4.4	11.9	6.2	11.0	0.38	59

Seasonal average metal concentrations in Bras d'Or waters can be estimated using a geochemical model similar to that developed by Petrie and Yeats (1990) for Halifax Harbour with additional terms for particle reactivity of the metals. Water transports for the model are taken from Gurbutt and Petrie (1995) and input data from various sources identified above. The model uses partition coefficients (K_d's) to estimate the fractionation of metals between dissolved and particulate forms, and estimates of particle settling velocities to estimate the flux of metals to the sediments. In the absence of extensive measurements of contaminant concentrations in Lake waters, results from models such as this give some estimate of concentrations that may be expected. Model results for dissolved and particulate Al, Cd, Cu, Fe, Pb, Ni and Zn concentrations in the 20 boxes of the Gurbutt and Petrie water circulation model are shown in Table VI. Arsenic was entirely in solution and varied from 1.0 to 1.2 µgL^{-1}. For Cd, Cu, Pb, Ni and Zn, the agreement between the model results and the very few observations that have been made is good (results generally agree within a factor of 2). The model seriously overestimates dissolved Fe in the North Basin but underestimates concentrations in Whycocomagh Bay. There are no observations for Al and As available for comparison with model predictions. The model can also be used to estimate metal concentrations in material settling out of the water column (Table VII). The predicted concentrations in sedimenting material are within the ranges for sediments in the Lakes listed in Table III or those for Nova Scotia embayments (Loring *et al.*, 1996), except for Cd which is high by a factor of approximately 2-4. The model is very much dependant on the metal concentrations in water flowing into the Lakes through the Great Bras d'Or Channel (see Table V for the relative importance of various input terms). For suspended particulate material (SPM) and the particulate dominated metals Al and Fe, this input is not well constrained. The limited data suggest that these inflowing waters have rather high (1.8 mgL^{-1}) concentrations for predominantly inorganic SPM. Lower SPM concentrations or SPM with a more biogenic character would reduce the inputs substantially and provide a better agreement with observations for Fe.

Table VI Model predictions of summer dissolved and particulate water column concentrations of trace metals for each box of the Gurbutt & Petrie (1995) model. All concentrations in µg L^{-1}. (diss = dissolved, part = particulate, Btm = bottom)

Location		Al	Cd	Cu	Fe	Pb	Ni	Zn
Whycocomagh W								
0-10 m	diss	0.19	0.022	0.39	0.25	0.0079	0.29	0.50
	part	3.4	0.0005	0.018	2.7	0.0072	0.013	0.023
10-Btm	diss	0.18	0.021	0.38	0.24	0.0076	0.28	0.48
	part	3.4	0.0005	0.018	2.7	0.0072	0.013	0.023
Whycocomagh E								
0-10 m	diss	0.23	0.022	0.39	0.30	0.0084	0.30	0.50
	part	4.1	0.0005	0.018	3.2	0.0077	0.014	0.023
10-Btm	diss	0.21	0.020	0.36	0.27	0.0078	0.28	0.47
	part	4.1	0.0005	0.018	3.2	0.0077	0.014	0.023
West Bay								
0-10 m	diss	0.1	0.021	0.26	0.10	0.0046	0.24	0.41
	part	1.7	0.0005	0.011	1.1	0.0041	0.011	0.018
10-Btm	diss	0.16	0.023	0.27	0.16	0.0056	0.26	0.43
	part	3.0	0.0005	0.013	1.9	0.0054	0.013	0.021
East Bay								
0-10 m	diss	0.06	0.019	0.21	0.06	0.0037	0.19	0.34
	part	1.1	0.0004	0.009	0.6	0.0032	0.008	0.015
10-Btm	diss	0.10	0.022	0.25	0.10	0.0044	0.25	0.41
	part	1.9	0.0005	0.012	1.1	0.0042	0.012	0.020
St. Andrew's Channel								
0-10 m	diss	0.11	0.021	0.23	0.10	0.0046	0.23	0.38
	part	1.9	0.0005	0.010	1.1	0.0041	0.010	0.017
10-50 m	diss	0.35	0.023	0.28	0.35	0.0077	0.28	0.45
	part	7.3	0.0006	0.014	4.4	0.0080	0.015	0.023
50-Btm	diss	0.33	0.023	0.28	0.33	0.0073	0.28	0.45
	part	6.8	0.0006	0.014	4.1	0.0076	0.014	0.023
St. Patrick's Channel								
0-10 m	diss	0.28	0.022	0.38	0.35	0.0090	0.30	0.50
	part	5.1	0.0005	0.018	3.9	0.0083	0.014	0.023
10-Btm	diss	0.55	0.024	0.33	0.60	0.011	0.31	0.50
	part	13	0.0007	0.019	8.3	0.013	0.018	0.029
Bras d'Or Lake								
0-10 m	diss	0.14	0.022	0.25	0.14	0.0052	0.24	0.41
	part	2.5	0.0005	0.011	1.5	0.0047	0.011	0.018
10-Btm	diss	0.42	0.023	0.28	0.43	0.0086	0.29	0.46
	part	8.9	0.0006	0.015	5.4	0.0091	0.015	0.024
North Basin								
0-15 m	diss	0.56	0.023	0.29	0.58	0.0094	0.27	0.45
	part	12	0.0006	0.015	7.4	0.010	0.015	0.024
15-30	diss	1.2	0.025	0.31	1.2	0.016	0.32	0.50
	part	39	0.0010	0.025	24	0.025	0.025	0.040
30-Btm	diss	1.2	0.025	0.31	1.2	0.016	0.32	0.50
	part	39	0.0010	0.025	24	0.025	0.025	0.040
Great Bras d'Or Channel								
0-15 m	diss	0.83	0.023	0.29	0.84	0.012	0.29	0.46
	part	20	0.0007	0.018	12	0.014	0.018	0.028
15-Btm	diss	1.4	0.025	0.32	1.5	0.018	0.33	0.51
	part	52	0.0011	0.029	32	0.031	0.029	0.046

Table VII Model predictions of metal concentrations in settling particulate matter (μg/g).

Location	Al	As	Cd	Cu	Fe	Pb	Ni	Zn
Whycocomagh W	7100	3.0	1.0	38	5700	15	28	48
Whycocomagh E	8300	3.0	1.0	36	6500	16	28	47
West Bay	6200	3.5	1.1	27	3900	11	26	43
East Bay	4000	3.6	1.1	25	2400	9	25	41
St. Andrew's Ch	13100	3.5	1.2	28	7900	15	28	45
St. Patrick's Ch	21800	3.6	1.2	33	14400	22	31	50
Bras d'Or Lake	16800	3.6	1.2	28	10300	17	29	46
North Basin	49200	3.6	1.2	31	30000	32	32	50
Great Bras d'Or	58100	3.6	1.3	32	35300	35	33	51

Summary

The isolation of the Bras d'Or Lakes from shelf waters, the relatively small watershed, the variations in basin size and depth, and the size of connections between different basins are all factors that lead to the creation of a number of different chemical environments within the Lakes. For the Lakes as a whole, the relatively small amounts of nutrients delivered by rivers and the small inputs of nutrients from the shelf that can be brought in through the Great Bras d'Or Channel only support a relatively low level of natural biological productivity. Nutrient distributions at the end of winter before the onset of the spring bloom are unknown. Collection of winter data will provide actual measurements of nutrient concentrations prior to the spring bloom and allow a better understanding of the factors that control the concentrations and variability of nutrients in the deep basins of the Lakes. The Lakes as a whole should be relatively unaffected by new inputs of nutrients from human activities and are at low risk for eutrophication. However, localized build-ups of nutrients, including inputs from sewage, agriculture and aquaculture, have already affected the water quality of some microenvironments in the Lakes. Sites like the west end of Whycocomagh Bay and the many barachois ponds are most susceptible to such eutrophication, which is evident in reduced oxygen concentrations or even anoxia, and which may be accompanied by bacterial contamination that results in closures to shellfish areas and restrictions on recreational use. The available data on persistent organic and heavy metal contaminants are limited. A more comprehensive picture of contaminants in the Lakes will require a large sampling program that gives better spatial and temporal coverage including analyses for more contaminants (especially organic ones). However, based on the data now available, there is no indication that any persistent organic or heavy metal contaminants are a concern within the Lakes at present concentrations in water, sediments or biota. Overall, the environmental quality is very good. This status is a result of the small population density and the very limited industrial development around the Lakes. However, this relatively pristine character of the Lakes does not imply that they are immune to environmental degradation: any management decision must consider potential impacts for both the entire Lake system and the particular microenvironments that may be involved. Maintaining or improving the environmental quality of the Lakes will require careful management of current and future activities in the Lakes and their watershed.

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OVERVIEW OF THE ECOLOGY OF THE BRAS D'OR LAKES WITH EMPHASIS ON THE FISH

TIMOTHY C. LAMBERT
Marine Fish Division
Fisheries and Oceans Canada
Bedford Institute of Oceanography
Dartmouth, Nova Scotia

In this review of biological research in the Bras d'Or Lakes, groundfish trawl surveys from 1952, 1967 and 1999/2000 are compared and changes in abundance and distribution of major groundfish species are noted. The most common species were winter flounder (*Pseudopleronectes americanus*) and cod (*Gadus morhua*). The biggest change over the nearly 50 year span of these investigations was in the abundance of American plaice (*Hippoglossoides platessoides*) which used to be very common in the Lakes but were rare in recent surveys. The Lakes contain at least one, and probably two, resident populations of cod and are home to a population of spring-spawning herring. The unique nature of the Bras d'Or Lakes is emphasized in relation to the diversity of species they contain. Glacial relicts, survivors since the last ice age, can be found within a few kilometres of warm temperate species, persisting since the 'climatic optimum'. The Lakes are ideally suited for ecosystem studies, for in addition to their unique biology, they are readily accessible and can be easily sampled on a daily basis.

Ce document passe en revue les recherches biologiques effectuées par le passé dans les lacs Bras d'Or et présente les résultats d'études récentes et en cours. Nous comparons les relevés du poisson de fond réalisés en 1952, en 1967 et en 1999/2000 en notant les changements dans l'abondance et la répartition des principales espèces de poisson de fond. Dans tous ces relevés, les espèces les plus courantes étaient la plie rouge (*Pseudopleronectes americanus*) et la morue (*Gadus morhua*). Le plus important changement observé sur les 50 ans que couvrent ces études a touché la plie canadienne (*Hippoglossoides platessoides*), que l'on trouvait très couramment dans les lacs par le passé mais qui était rare dans les relevés récents. Les lacs contiennent au moins une et probablement deux populations résidantes de morue et une population de hareng qui fraie au printemps. Le document met l'accent sur la relation entre la nature particulière des lacs Bras d'Or et la diversité des espèces qu'ils abritent. Des espèces reliques de l'âge glaciaire y vivent à quelques kilomètres d'espèces caractéristiques d'un climat tempéré chaud qui persistent depuis la période de réchauffement médiéval. Les lacs se prêtent parfaitement à des études écosystémiques, car, en plus d'être uniques sur le plan biologique, ils sont faciles d'accès, et on peut aisément y effectuer des échantillonnages quotidiens.

Introduction

Many people are surprised to learn that the Bras d'Or Lakes are not actually lakes in the usual sense of the word, that is, a body of fresh water. At first encounter they have every appearance of lakes, being bordered by low mountains to the west and rolling hills to the east and, unlike the nearby ocean, appear to have no tide. However, a taste of the water and an examination of the fish caught by youngsters off a dock will quickly dispel this first impression. The water is distinctly salty and the fish on the dock will probably be a cunner (sea perch), cod or even a mackerel. This inland sea, one of Canada's scenic highlights, sustains an ecosystem which is unique in many respects.

The Bras d'Or Lakes are situated in Cape Breton Island at the northern end of Nova Scotia. This body of water of about 1,100 km^2 is essentially an enclosed estuary with three outlets to the sea. The Great Bras d'Or Channel and the Little Bras d'Or Channel connect with Sydney Bight to the north, and St. Peter's Canal gives access to Chedabucto Bay to the south (Fig 1). Only the Great Bras d'Or Channel is large enough to permit any significant exchange of water. The Bras d'Or Lakes watershed is about 2500 km^2; this area added to that of the Lakes themselves gives a total catchment area of 3600 km^2 (Krauel, 1976).

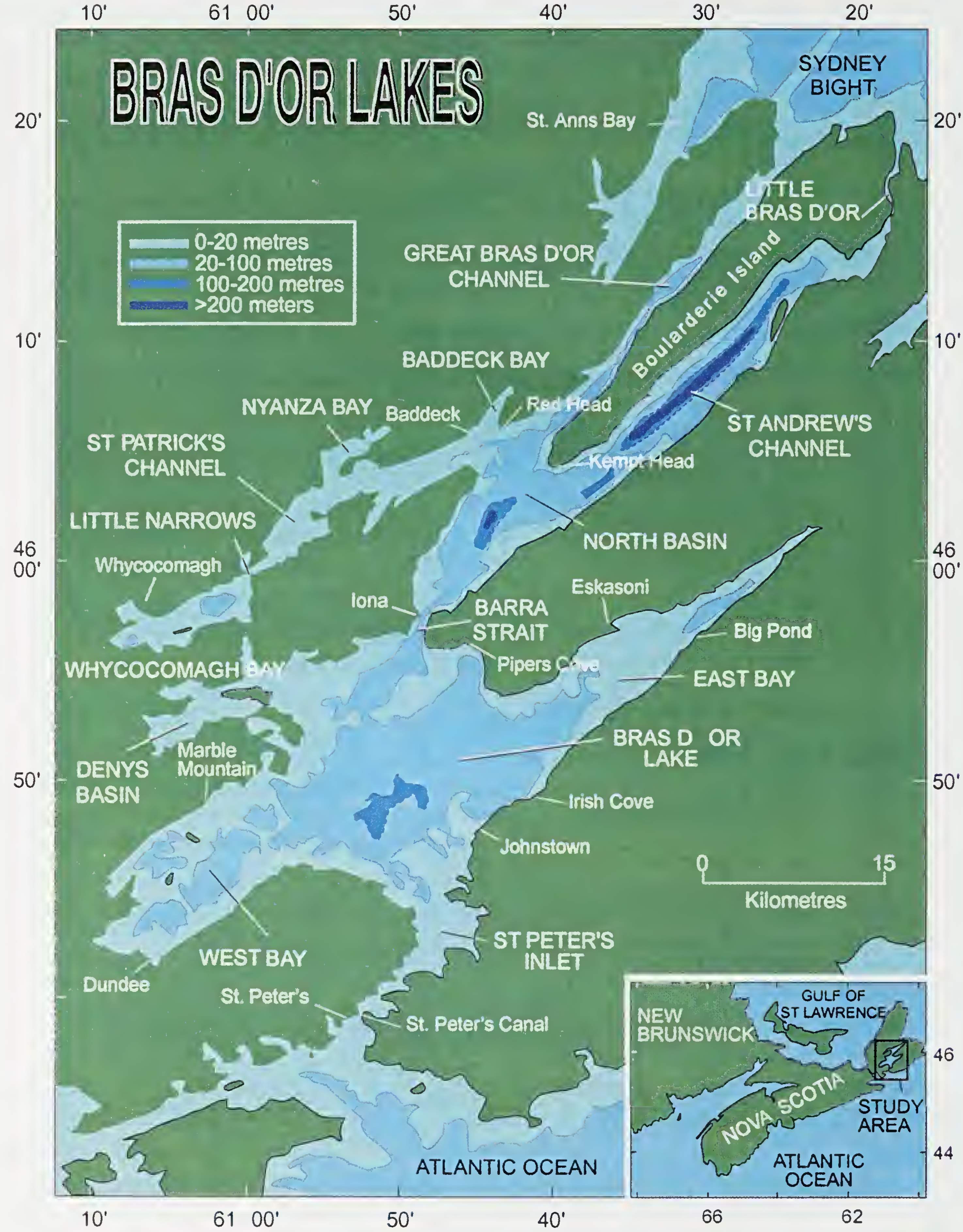

Fig 1 Map of the Bras d'Or Lakes indicating places mentioned in the text.

Input from six rivers and restricted access to the ocean keeps salinity in the range of 20 to 26, whereas, sea water just outside the Lakes in Sydney Bight ranges from about 28 to 32. The Lakes are usually ice covered in the winter and surface waters often exceed 20° C in the late summer, particularly in smaller, shallow bays (Petrie and Bugden, 2002).

The waters of the Bras d'Or Lakes are characterised by a two-layer system; a low salinity surface layer which has a wide annual range in temperature and a lower layer of higher salinity in which temperature range is much less pronounced. In general, surface water moves toward the entrance of the Lakes and out into Sydney Bight and is replaced with outside oceanic water which enters the Lakes near the bottom and flows underneath the surface layer (Krauel, 1976; Petrie and Bugden, 2002). With the exception of restricted channels, there is little mixing between these layers except for winter months when higher winds and wave action disrupt the stability of this system. In some areas where currents and exchange rates are very low, the amount of dissolved oxygen can become quite depressed and in Whycocomagh Bay, anoxic (no oxygen) conditions exist (Petrie and Bugden, 2002;Strain and Yeats, 2002).

A wide range of habitats, with bottom types ranging from rocky through gravel and sand to mud, can be found. These include marshy flats, "barachois" (small, shallow pond-like embayments, more or less cut off from the main lake by a sandbar), bays, inlets of various depths (some well-flushed and others anoxic), deep basins and a trench about 280 m, a depth matched only beyond the edge of the continental shelf. Given the diversity of habitats it is not surprising to find that the Bras d'Or Lakes are home to a wide variety of marine life. The species within the Lakes are, in general, characteristic of those occurring along Nova Scotia's Atlantic coast. However, the Bras d'Or is probably unique in that it is also home to both warm and cold water species which are rare in this part of the world.

Ecologists divide the earth into regions, which have characteristic faunal assemblages, which can be related to climatic conditions. In the Northern Hemisphere, these zoogeographical regions, ranging from cold water to warm, are Arctic, boreal, temperate and tropical. The boundaries between these regions are not distinct and arctic-boreal and boreal-temperate borders in the western North Atlantic tend to fluctuate according to the season; transition zones between zoogeographical areas are broad. Nova Scotia is in the boreal region, which roughly extends from south-east Labrador in the north to Cape Cod in the south (Ekman, 1953). Although a distinct assemblage of animals dominates this zone, Arctic species are intermittently carried south into the boreal zone by the Labrador Current, and conversely, temperate and even subtropical species are regularly carried far north of their normal ranges by the Gulf Stream. Most obvious of these transient visitors are pelagic creatures such as the sunfish and sea turtle. Less noticed because of their smaller size, but more common, are planktonic transients. In summary, there is no smooth, transition of northern species to southern species in this area of the world (Bousfield and Thomas 1975).

Many of the fish in the Bras d'Or Lakes are resident there and most are demersal or bottom living. Migratory pelagic (living in surface and mid-waters) species, such as mackerel, herring and salmon, are seasonal visitors to the Lakes. Species that do, or did, support commercial fisheries are winter flounder and herring. The winter flounder fishery ended in 1992 with the barring of commercial draggers from the Lakes (MacIsaac, 2001), and the spring herring fishery was stopped in 1999 because of the imminent collapse of the stock, most likely due to overfishing. Cod, mackerel, smelt, and eel support limited recreational fishing.

Some invertebrates fished in the Bras d'Or Lakes are lobsters, oysters, scallops and rock crab. Lobsters are fished in most rocky areas throughout the Lakes but present landings are poor, which may be a result of overfishing or because of poor larval survival resulting from reduced salinity (Tremblay, 2002). Scallop and rock crab fishing is limited to a small area at the north end of the Great Bras d'Or Channel immediately adjacent to Sydney Bight. Here, the higher salinity bottom water entering the Lakes from the Bight is salty enough to support these 2 species, but probably not farther into the Lakes, since it becomes progressively diluted by low salinity Lakes' water. Oysters, once common throughout the Bras d'Or Lakes, have been seriously depleted on public beds due to overharvesting (Dennis, 2001) and are now found in quantity only at lease sites, where they form the basis of an important and growing aquaculture industry. The presence of the green crab, a recently introduced non-native species, is of great concern since it is known to feed voraciously on juvenile bivalve molluscs such as clams and oysters (Tremblay, 2002). Rainbow trout and salmon are also farmed in the Lakes.

Despite the cultural and economic importance of the Bras d'Or Lakes to Cape Breton Island, and their accessibility, we have but a rudimentary knowledge of their biology. However, the limited research that has been carried out does seem to indicate that the Lakes are unique, at least biologically. They have many similarities with adjacent Sydney Bight, but also have intriguing differences. This paper will review what is known of the Lakes' biology, highlighting unique aspects, and as well will examine the groundfish community, comparing recent survey work to surveys carried out over 30 and 50 years ago.

Previous Studies

Much of the research conducted within the Bras d'Or Lakes in the past was motivated by an interest in aquaculture. Some of the results of these early studies were presented at a conference in 1975 (McKay, 1976), where information on water chemistry (Young, 1976); physical oceanography (Krauel, 1976); primary production (Wright, 1976); and marine biology (Black, 1976) were given. For those interested in engineering design of culture systems, the remainder of the proceedings are a useful reference. A description of the Bras d'Or region and a comprehensive bibliography of literature relating to the Bras d'Or Lakes is being prepared by Kenchington and Carruthers[1] on behalf of the Unama'ki Institute of Natural Resources.

Primary Production Phytoplankton (planktonic plants) are very important in marine ecosystems, for they are the base food source upon which virtually all marine life depends. Geen (1965), Geen and Hargrave (1966), Wright (1976) and recently Strain and Yeats (2002) suggest that the level of phytoplankton growth (primary production) in the Lakes is low, since nutrient input was small. Strain and Yeats (2002) estimate that the contribution of sewage and other man-made sources of nutrients is minor; although, in some localised areas, such as barachois and the western end of Whycocomagh Bay there is sufficient build up, together with natural nutrients, to cause eutrophication (explosive growth of plant life which chokes waterways). The resulting anoxic conditions kill marine organisms and produce sulfides during decomposition.

Plankton. The best way to determine the range of species that live in the ocean is to tow a plankton net through it. Many animals that live in the sea, whether they are fishes or invertebrates, or whether they live on the bottom or swim freely in the water column, have a planktonic stage that drifts with the current. This may be an egg, a larva, or both. Thus in a plankton sample it is possible to find larval stages of animals as diverse as fish, clams, oysters, scallops, starfish, sea urchins, marine sea worms, barnacles, crabs and lobsters. These are mixed with microscopic animals e.g. copepods, whose entire life span is planktonic.

The National Museum of Canada undertook a series of investigations of the benthos and plankton in the Lakes during the summer of 1981. Shih *et al.* (1988) directed their attention to the copepod fauna, tiny crustaceans that are the food source for many larval fish and even some adult fish, which strain them from the water with specialised gill rakers. Fifteen species of copepods (Fig 2) were found, but these species were not evenly distributed. *Pseudocalanus minutus, Oithona similis, Temora longicornis* and *Tortanus discaudatus* were the most common and found throughout the Lakes. Bras d'Or Lake had the lowest diversity with virtually only these 4 species present. St. Andrew's Channel had the highest diversity including the only occurrences of *Anomalocera opalus, Calanus finmarchicus, Calanus hyperboreus* and *Microcalanus pusillus* (a cold water species common in the Arctic).

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[1] An unpublished document "Unamapaqt: A description of the Bras d'Or marine environment" commissioned by the Unama'ki Environmental Committee of the Union of Nova Scotia Indians

Plankton samples were collected in the Lakes by the federal Department of Fisheries and Oceans (DFO) during the 1990s, generally during May and early June. The focus

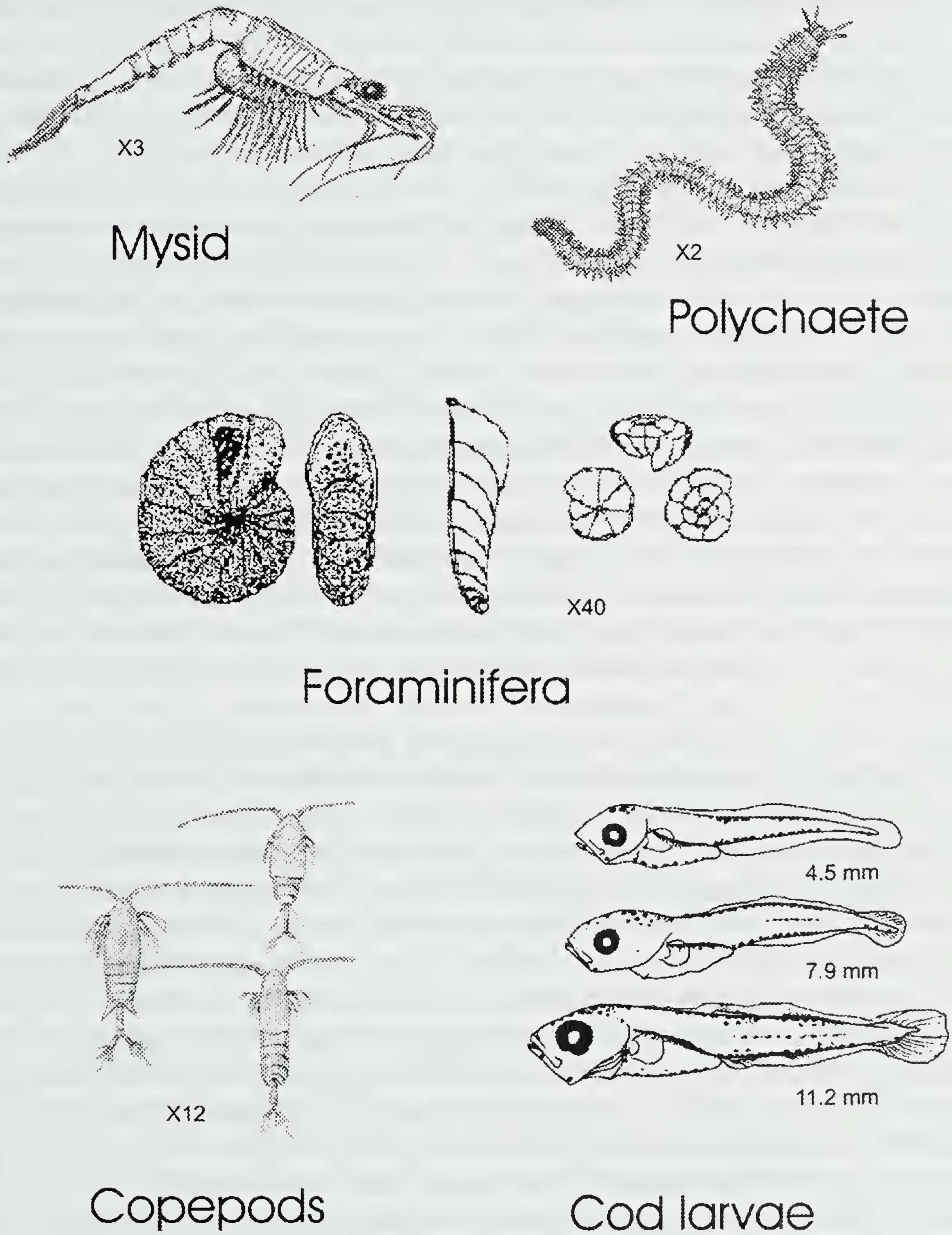

Fig 2 Selected invertebrates and fish larva occurring in the Lakes and mentioned in the text.

of this work was to determine time and location of spawning of fish species through collection of eggs and larvae. In 1991, as part of a cod egg survey of Sydney Bight, a few tows were made in the Bras d'Or Lakes. Later, a dedicated survey was made of the Lakes during May and June of 1996. In 2000, an annual plankton survey was begun as part of a cooperative venture between the DFO and the Eskasoni Fish and Wildlife Commission (EFWC). The samples are being analysed at EFWC and results will be reported elsewhere; however, a few highlights of their ichthyoplankton (larval fish) content bear mentioning. The most abundant fish eggs found were those of the four-beard rockling (*Enchelyopus cimbrius*), cunner (*Tautogolabrus adspersus*), window-pane flounder (*Scophthalmus aquosus*) and mackerel (*Scomber scombrus*). The most common fish larvae were four-beard rockling, winter flounder (*Pseudopleuronectes americanus*), cod (*Gadus morhua*) and smelt (*Osmerus mordax*). Some species known to frequent the Lakes were absent or poorly represented in the samples due to the timing of the surveys. Cod eggs in an early stage of development were scarce because the surveys were too late to catch the peak of cod spawning which apparently occurs in late February and early March; however, cod larvae (Fig 2) were common. On the other hand, the surveys occurred just as mackerel were beginning to spawn; hence their eggs were plentiful but larvae were not, since few eggs had yet hatched.

Benthic Invertebrates During groundfish trawl surveys in 1951-1952 (Black, 1976), 1967 (MacDonald, 1968) and 1999-2000 (this paper), the presence of the larger bottom dwelling invertebrates was documented. Tremblay (2002) presents details on these species and a brief overview of species he did not include will be presented here.

Mysid shrimps Mysid shrimps (Fig 2) live in close association with the ocean floor and are an important food source for many bottom-feeding fish. Black (1958) studied these small shrimps from 3 locations in the Bras d'Or (see 'Groundfish trawl surveys' below). He identified 5 species, the most common of which were *Neomysis americana* and *Mysis stenolepis*. These two were found in all parts of the Lakes and are boreal inshore forms that have a wide temperature and salinity tolerance. *Mysis mixta* and *Erythrops erythrophthalma* are Arctic-boreal forms which avoid warm water and were found in the cold water of deep areas, although they moved to shallower depths in the winter when surface waters cooled. The fifth species, *Mysis oculata* is a true Arctic animal and is generally found in shallow polar regions. Here, at considerable distance from its normal home range, it survives in the cold, deep waters of the Lakes.

Polychaete worms Fournier and Pocklington (1984) identified more than 70 species of polychaetes (marine worms) from benthic samples taken from all parts of the Lakes (Fig 2). The Great Bras d'Or Channel had the greatest number of species with 43, 19 of which occurred only in the Channel, and not in other areas of the Lakes. They recognised a range of zoogeographical affinities from warm water temperate species through boreal to Arctic. St. Patrick's Channel and Whycocomagh Bay had the poorest representation of polychaete worms with only 15 species recorded. Probably the most common polychaete found throughout the Lakes was *Euchone papillosa*. This worm constructs a slender clay-walled tube within which it lives. These tubes often form dense mats to which a small clam, *Hiatella arctica*, attaches (Fournier and Pocklington, 1984. One of the Arctic 'relicts' found in the Lakes was *Clymenura polaris*, whose occurrence here is the first record south of Davis Strait in the Arctic.

Foraminifera Vilks (1967) surveyed the foraminifera of the Bras d'Or Lakes (Fig 2). The tiny shells of these marine protozoa form a calcareous ooze which, over time, can fossilize and become the major constituent of chalk deposits. Foraminifera are closely associated with sediments, so Vilks classified the sediments of the Lakes and mapped their distribution. From coarse to fine, they ranged from boulders to clay, with fine clays being predominant in the deep basins and coarser elements being more common in shallower locations and areas of strong currents, such as the Great Bras d'Or Channel and the Barra Strait. He identified 39 species of foraminifera, groups of which he associated with specific sediment types. The Bras d'Or Lake assemblage was quite different from that of the northern extremity of the Great Bras d'Or Channel and adjacent Sydney Bight. In the Lakes, the most common species was *Eggerella advena* followed by *Trochammina squamata* and *Milliamina fusca*. On the whole, the Lakes' protozoan faunal assemblage was found to be very similar to that seen in St. Margaret's Bay and Mahone Bay, southwest of Halifax. However, *E. advena* and a less abundant group of foraminifera (Reophacidae) found in the Lakes are common in Arctic inshore waters.

Herring The Bras d'Or Lakes is considered home to at least one population of herring since spawning takes place there in the spring. (By convention, biologists have agreed that the area in which a species spawns will be regarded as its home). Opinions differ as to whether these herring move into the Lakes to spawn and then move out afterwards. Limited returns from a tagging program conducted in Sydney Bight (Sinclair *et al.*, 1980) support this view; three fish tagged in Sydney Bight were captured in Whycocomagh Bay and near Militia Point and a herring tagged in St. Ann's Bay, outside the Lakes, was caught off Pipers Cove in Bras d'Or Lake (Crawford *et al.*, 1982). However, some herring may reside in lakes as they have been caught there during the winter. To further complicate matters, autumn spawning herring have been found (Denny et at 1998); whether this group actually spawns in the lakes is not known. Until 1999 there was a spring fishery targeting the spawning herring; this began after ice break-up and lasted for 3-4 weeks. The main spawning areas were along the western shore of West Bay, Denys Basin, St. Peter's Inlet and off Eskasoni. However, in the last few years of the fishery it was apparent that, with the exception of a limited area near Malagawatch, herring had ceased to spawn south of the Barra Strait and the only egg deposition of note occurred in Baddeck Bay (Denny *et al.*, 1998). In recent years, mackerel, used traditionally as lobster bait, has become expensive; thus the use of cheaper herring as an alternative led to a substantial increase in its demand. The sudden increase in fishing effort on the declining Bras d'Or Lakes stock rapidly brought this herring population to the point of collapse and the fishery was ordered closed in 1999.

Crawford *et al.* (1982) studied the Bras d'Or Lakes spring-spawning herring in 1980 and 1981. They looked at adult characteristics and carried out egg and larval surveys at a spawning ground in Ross Cove within West Bay. They found that the Lakes herring differed from other herring in a number of characteristics. They were smaller at a given age than Atlantic coast or Northumberland Strait spring-spawners and differed in meristic counts (meristics refers to numbers of physical structures, such as fin rays, gill rakers, and vertebrae, which are useful in differentiating populations). A six year-old Bras d'Or Lakes female herring produced about 47,500 eggs and a nine year-old, about 165,250. This fecundity was on average about 8% higher than that of Northumberland Strait spring-spawning herring. Crawford and his team noted spawning in Ross Cove in early April at depths of only 1/4 m to 3/4 m; this is one of the shallowest on record for the Atlantic coast. The majority (80%) of eggs were deposited on the eelgrass (*Zostera marina*) and most of the remainder on sea lettuce (*Ulva lactuca*). A loss of 85% of the eggs was estimated and although some eggs were seen to have died, the majority of the reduction was thought to be due mainly to predation by winter flounder and to a lesser extent cod and perhaps even gulls, which were seen to congregate in the area. Herring eggs at Ross Cove began to hatch on April 27 and at peak hatching the density of larvae over the spawning bed was over 4,500 per cubic metre of water. The larvae were about 7 mm long at hatching and grew at a rate of about 1/4 mm a day.

Seaweed. During the summer of 1970, McLachlan and Edelstein (1971) established 45 sampling stations along the shores of the Bras d'Or Lakes to observe and collect seaweeds. They found that the marine algae were restricted to a narrow band from the shoreline down to 3 to 4 m depth. A total of 92 species and varieties were identified in their survey; 31 red algae, 31 brown algae, 23 green algae and 7 microscopic blue-green algae. Nowhere was the marine plant cover very dense and much of the bottom was unsuitable for attachment of seaweed, being muddy or made up of other loose material. One species however, which can root in this type of unconsolidated bottom, is the eelgrass, (*Zostera marina*), which is the most common marine plant in the Lake system. It occurred at all stations and also tended to grow at greater depths than other species. Three algal species were new records for Nova Scotia and one other, found in St. Andrew's Channel, had been only reported from the Sarema and Khiuma Islands in the former Soviet Union.

McLachlan and Edelstein (1971) recognised two seaweed associations in the Lakes; in one, the species were the same as those of the open Atlantic coast of Cape Breton, and in the other, the species were shallow warm-water plants characteristic of protected bays along the Northumberland Strait. The first group, mostly common brown seaweeds, were dominant in the Great Bras d'Or Channel and extended into St. Andrew's Channel, West Bay and the western part of East Bay. These species included the common rockweed or bladder wrack (*Fucus vesiculosus*), knotweed (*Ascophyllum nodusum*), kelp (*Laminaria agardii*), Irish moss (*Chondrus crispus*) and, similar to Irish moss, the leaf weed (*Phyllophora membranifolia*). These oceanic species died out as one moved farther into East Bay. In St. Peter's Inlet, the algal flora were sparse and resembled that of the upper reaches of East Bay. Only eelgrass and the whip-like, smooth cord weed, (*Chorda filum*) were found there. The warm water group of seaweeds were dominant in St. Patrick's Channel, Denys Basin and North Basin. This included sea lettuce (*Ulva lactuca*), the fern-like *Bryopsis hypnoides*, twig weed (*Ahnfeltia plicata*), the coarsely bushy red seaweeds, chenille weed (*Dasya pedicellata*) and graceful red weed (*Gracillaria foliifera*) and the finely bushy red seaweeds, banded weed (*Ceramium fastigiatum*), rough tangle weed (*Stilophera rhizodes*) and slippery tangle weed (*Sphaerotrichia divaricata*).

Uncommon morphological forms of some common seaweed species were found in the Lakes. Unusual bushiness, reduction or absence of flotation vesicles and colour variation were some of the anomalies recorded. McLachlan and Edelstein thought the wide range of environmental conditions (temperature, salinity, lack of tides and perhaps low nutrients) in the Lakes might be responsible for these aberrant forms.

Groundfish Trawl Surveys

Survey methodology 1951-1952. The Fisheries Research Board of Canada investigated the biology of the sealworm (*Pseudoterranova decipiens* Krabbe) from 1948 to 1953 within the Bras d'Or Lakes. As part of these studies Black (1976) conducted trawl surveys in the Lakes in 1951 (May to the end of December) and 1952 (May to August). He provided no details on the type of fishing gear used other than referring to it as a shrimp trawl. Thirty min tows were made regularly at 3 stations: Baddeck Bay (15 - 20m), Whycocomagh Bay (10 - 30m) and Kempt Head (55 -75m). In addition, a few additional sets were made along the lengths of the Great Bras d'Or and St. Patrick's Channels in June and July of 1952, respectively (Appendix/1).

Survey methodology 1967. In 1967, the Nova Scotia Department of Fisheries contracted a 40 ft commercial fishing boat to conduct a trawl survey of the Bras d'Or Lakes (MacDonald, 1968). A 3/4 number 35 Yankee trawl was used. The net had mesh of 41/2 in (11.4 cm) and was fitted with a 11/8 in (2.8 cm) mesh liner to retain small fish. The trawl headline length was 40 ft (12.2 m), foot rope length 54 ft (16.5 m) and height at mouth 7 ft (2.13 m) (Fig 3). Towing speed was approximately 2.5 knots (4.6 km per h). Between September 20 and November 16, 117 tows were made throughout most of the Lakes. Towing time varied in length, ranging from 25 to 120 min with an average of 75 min. Set position, depth, type of bottom and weight of fish by species were recorded; number of fish only was given when a particular species was scarce.

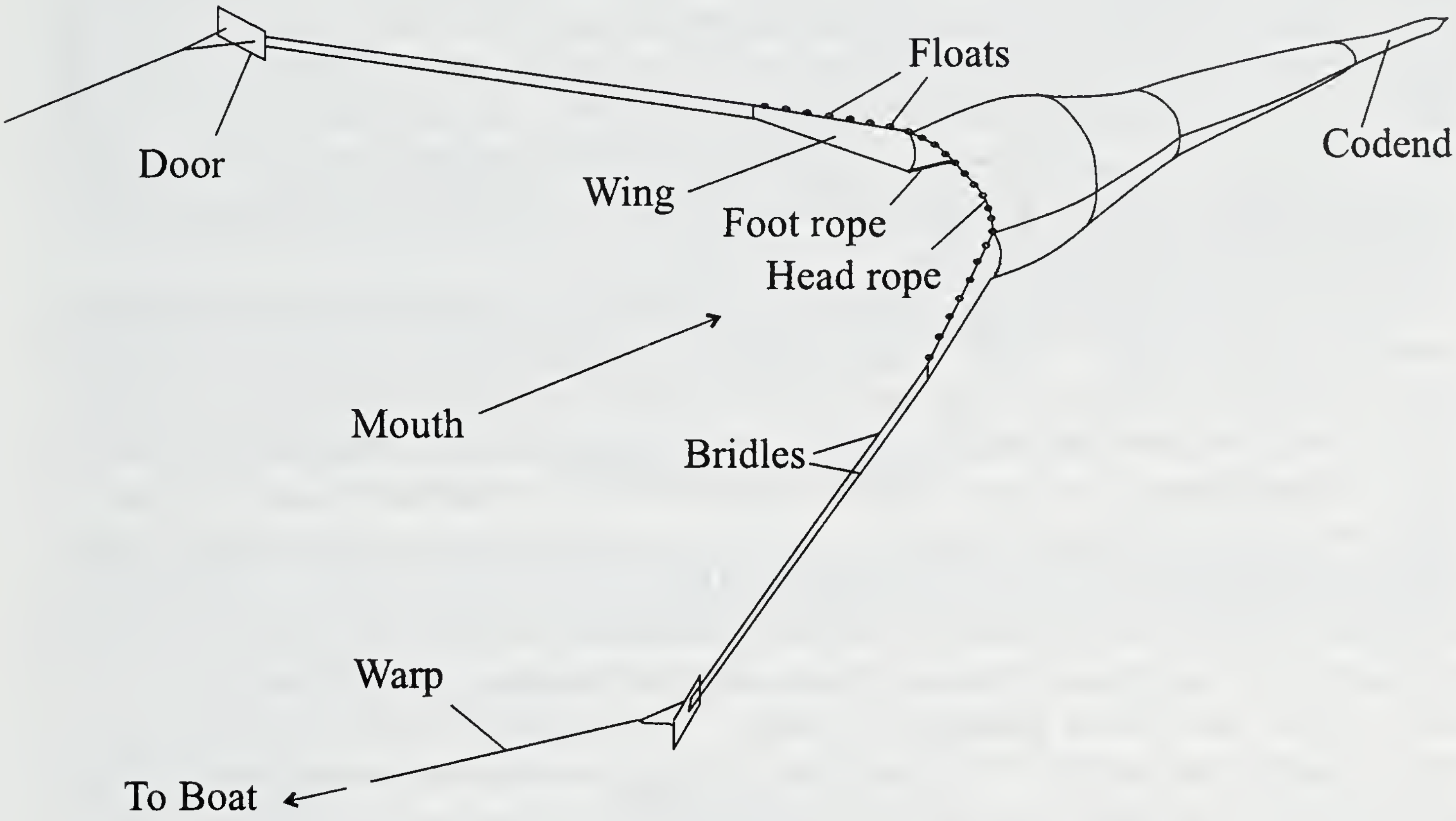

Fig 3 Components of a generalised bottom trawl net.

Survey methodology 1999-2000. In 1999, the EFWC, DFO and the 4Vn Sentinel Fishery Association (4VnSFA), began a cooperative 5 year investigation of the groundfish of the Bras d'Or Lakes. Including trawl, longline and ichthyoplankton surveys, these studies focussed on the biology of cod. Larval, juvenile and adult populations were sampled with a variety of gears. The DFO's 20 m CCGC Navicula carried out bottom trawling for 4 weeks during September and October, and plankton sampling in the late spring. A 4VnSFA longliner set gear in the Lakes once a month, except when prevented by ice. In addition, a tagging program was started in 2000 to investigate movement of cod within the Lakes and also to determine whether there is exchange of fish between the Lakes and Sydney Bight.

Groundfish were sampled with a small flounder trawl Fig 3. The head rope of the net was 50.5 ft (15.4 m), the foot rope (wire cored rope reinforced with chain) was 59.5 ft (18.1 m), the height of the wing at the attachment point to the net is 6 ft (1.83 m) and the height of the mouth opening of the net, 10 ft (3.05 m). The main mesh of the trawl was 5 in (12.7 cm) and the cod-end is equipped with a 1 in (2.54 cm) mesh liner to retain juvenile fish. The trawl was towed 1 nautical mi (1.853 km) at a speed of 2.5 knot (4.6

km per h), thus the tow duration was approximately 25 min. Total weight, number and length frequencies were recorded for all species of fish. In addition, for cod only, otoliths (ear bones used for ageing the fish) were extracted, maturity determined and stomach contents and fullness assessed. Also, the bottom invertebrate fauna captured by the trawl were identified, counted and weighed (Tremblay, 2002). Water temperature and salinity data were collected with a conductivity / temperature / depth (CTD) profiler.

Comparison of surveys. When comparing the three surveys, several points should be kept in mind. Although year-specific data are available for the 1999/2000 surveys, they were combined and, with one exception, no attempt was made to look at annual variation. This is because the 1967 survey represents 1 y and although Black's (1976) earlier survey represents 2 y of sampling, his data are presented in combined form. Black's survey is limited in geographical extent, whereas the other 2 cover most of the Lakes. On the other hand, Black sampled three seasons, spring to autumn, whereas the later two surveys sampled only the autumn. The 1967 survey (MacDonald, 1968), which extended to mid November, was longer than the 1999/2000 one, which ended in mid October. However, 60% of the 1967 sets coincided with the time period sampled by the 1999/2000 survey.

A trawl net is towed behind a boat by two cables (warps) which are spooled on two drums of a large winch. These warps are led, one to each side of the boat, through a series of pulleys and then connected to trawl 'doors' (sometimes called otter boards). Each of the doors are attached to bridles, which in turn fasten to the wings of the net (Fig 3). When fishing, the head rope of the net, which is fitted with floats, lifts the top of the net thereby opening its mouth. The foot rope, being longer than the head rope, drags along the bottom in an arc beneath and behind the leading edge of the net; thus the top overhangs the bottom of the net and prevents any upward escape of fish which encounter the foot rope. The trawl doors, angled like kites, spread the mouth of the trawl as they are towed through the water. The width of the mouth of the net is constrained by the length of the head rope (shorter than the foot rope), and its height is a function of the sideways pull of the trawl doors and the upward lift of the floats on the head rope. Based on measurements and mesh size (MacDonald,1968), the trawl net used during the 1967 survey was very similar to the net used in the recent EFWC/DFO surveys.

Fish encountering the wings of a trawl net are herded toward its centre. Thus the effective swept area of the bottom is generally considered to be the distance between the outer ends of the wings multiplied by the distance towed. Unfortunately, MacDonald (1968) does not indicate the length of the wings of the trawl net she used. Therefore, in the following calculations I have assumed that the wings of the trawl nets used in the two surveys were the same and have based any differences on the trawl net body measurements. I estimated the mouth width of the nets by representing the area of the mouth as two back to back right triangles whose angled tops approximate the head rope and whose coincident apexes correspond to the height of the net mouth. Their combined bases form the top of a narrow rectangle beneath, whose span will be equivalent to the width of the net mouth. This distance is easily calculated and indicated that the MacDonald (1968) trawl net mouth width was narrower, and so her trawl would have swept a smaller area than that used in the 1999/2000 surveys. Accordingly, based on net configuration, I have estimated that, over a given distance, the net used in the 1999/2000 surveys would catch about 1.3 times more fish than that used in the 1967 survey.

MacDonald's (1968) data are expressed as lb per hour. Although the towing speed is listed as 2.5 knots, the actual speed-over-ground (as opposed to boat speed through the water) when towing a net can vary considerably. Maintaining a constant towing speed requires continual monitoring of speed-over-ground (with positioning devices such as GPS) and continual adjustment of boat engine speed to compensate for varying wind, current and trawl net drag (related to degree of bottom roughness). To illustrate, the average time for a one nautical mile tow with CCGC Navicula was 27 min (Std. Dev. 4.3 min). The longest duration for this distance was 38 min, and the shortest, 20 min. The 1967 survey boat carried no electronic navigational equipment other than a depth sounder, so an accurate means of determining distance of tow was not possible. To compare with 1999/2000 catch rates, those for the 1967 survey were converted to kg per tow using tow duration and a towing speed of 2.5 knots and then adjusted by the 1.3 conversion factor. These estimates would be subject to the errors discussed above, and although the calculated value for any specific tow might be inaccurate, the average value for all tows should be reasonable.

Where certain species were scarce in 1967, MacDonald (1968) expressed their quantity by number rather than by weight. For comparison, average individual species weights were calculated using 1999/2000 data: the conversion weights were; windowpane flounder - 210 g, white hake - 201.3 g, and yellowtail flounder - 191.6 g.

Trawl Survey Results

1951-1952 Black (1976) lists 22 species found during his investigation (Table I). Most common were winter flounder, white hake, Atlantic cod and American plaice;

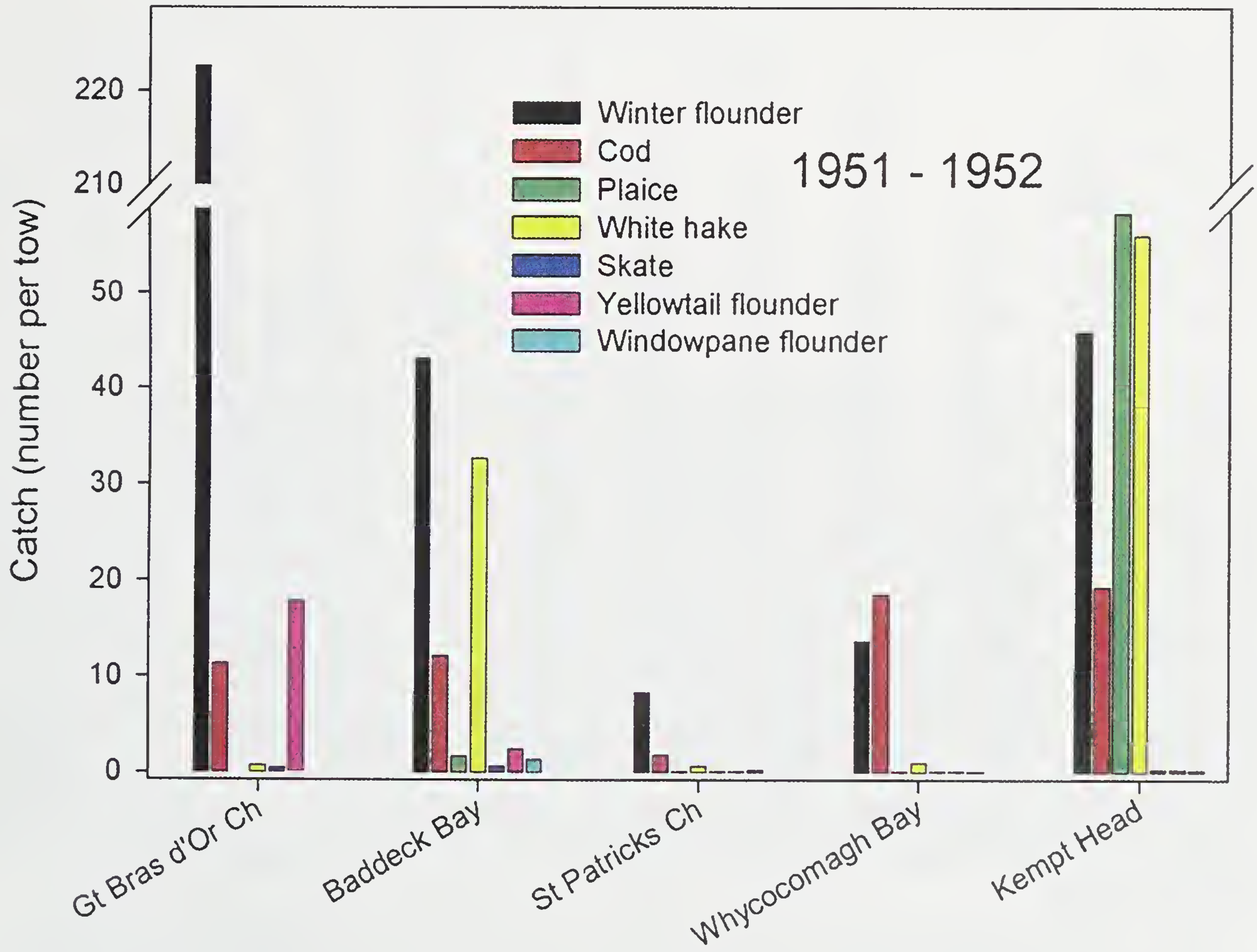

Fig 4 Trawl catch, 1951-1952 by area.

some of the scarcest were eels, haddock, four-beard rockling, dogfish, and ocean pout. Distribution of some of the more important species in the catch can be found in Fig 4 and Table AII. Of the 3 principal sites, Whycocomagh Bay had the lowest overall catch rate and Kempt Head the highest. The highest catch rate was of winter flounder in the Great Bras d'Or Channel in June of 1952. Smelt were quite common in the catch, particularly in shallow areas along St. Patrick's Channel in July of 1952. Although they are not considered a bottom fish and tend to be found swimming nearer the surface, smelt are sufficiently abundant that they are often captured as the net passes through surface layers at the beginning and end of a tow.

Table I Total catch of groundfish taken in the Bras d'Or Lakes, 1951-52. Black (1976).

Species	Total catch (number)
Winter flounder	7,010
White hake	4,616
Cod	2,448
Plaice	2,247
Smelt	517
Yellowtail flounder	307
Cunner	260
Windowpane flounder	113
Herring	70
Mailed sculpin	70
Skates	60
Pollock	59
Longhorn sculpin	22
Alewife	19
Eel	12
Alligatorfish	7
Spiny dogfish	5
Sea raven	3
Shorthorn sculpin	3
Fourbeard rockling	2
Haddock	2
Ocean pout	1

Black noted seasonal changes in the distribution of fish that he thought might be related to temperature. Cod and plaice numbers diminished with increasing bottom temperature in Baddeck Bay during the summer and while abundant at the deeper Kempt Head station during the summer, diminished there during the winter and early spring. Black suggested a movement from the deeper area to a shallower one, perhaps Baddeck Bay, where temperature might be more suitable for these species. He also noted seasonal changes in abundance of white hake, cunner and winter flounder. Hake apparently moved away from the deeper, Kempt Head station to the shallower, Baddeck Bay station in the late summer and autumn. The number of cunner and winter flounder increased rapidly in Baddeck Bay with increasing bottom water temperature. In the case of winter flounder, the increase was mainly in smaller size-classes. Black noted that the length frequency of white hake also changed in favour of smaller fish during autumn.

1967 MacDonald (1968) found a total of 18 species of fish with American plaice, winter flounder and Atlantic cod being the most abundant (Table II, Fig 5). As Black had found, eels, four-beard rockling, and pout were rare. However, haddock and dogfish that were scarce in 1951/52 were not caught at all. Pollock, which had appeared in moderately low numbers only at the Kempt Head station, were absent.

Table II Total catch of groundfish taken in the Bras d'Or Lakes, 1967. MacDonald (1968).

Species	Total catch (kg)
Plaice	3,334
Winter flounder	3,008
Cod	2,756
Skate	145
Yellowtail	86
Smelt	40
White hake	15
Windowpane flounder	*14 (67)
Sculpins	*10 (32)
Perch (probably Cunner)	10
Witch flounder	*6 (10)
Herring	1
Gaspareau	1
Dollarfish	<1
Eel	<1
Eel-pout	<1
Four-beard rockling	<1
Silverside	<1

* Estimated weight based on number of fish (in brackets) reported.

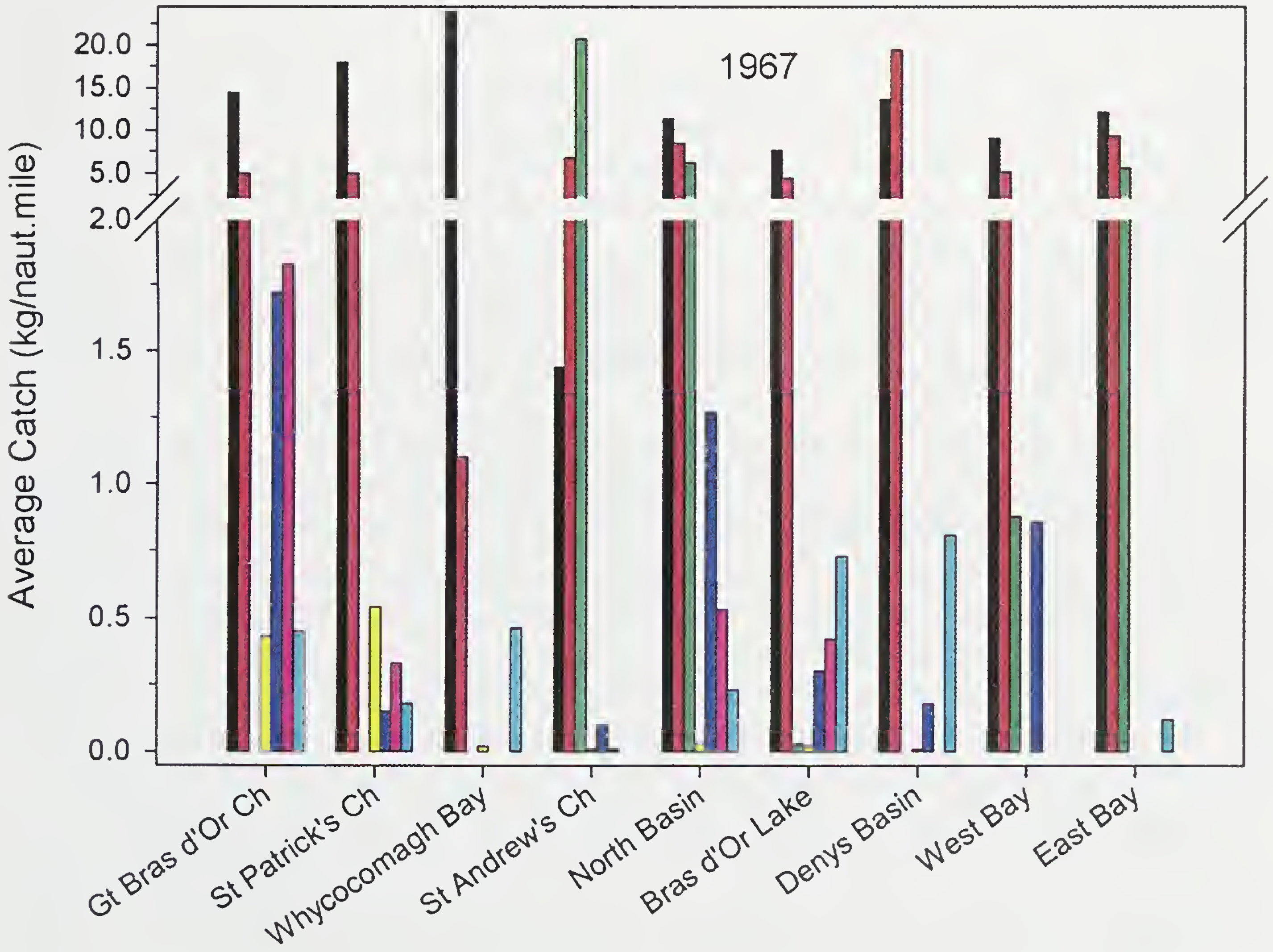

Fig 5 Trawl catch, 1967 by area. Legend for Fig 4 also applies to this Fig.

1999/2000 Surveys A total of 25 species were taken in these surveys, the most abundant being winter flounder and Atlantic cod (Table III, Fig 6). The most noticeable difference between this survey and those of earlier years was the large decrease in the number of American plaice. Eels, pollock, haddock, dogfish and pout, present in the two earlier survey periods, were not caught. Smelt, as in earlier surveys, continued to be a common part of the catch and also, as previously, were found in abundance in St. Patrick's Channel. Smelt spawn in fresh water, therefore, it is not surprising to find them in this Channel as it receives most of the fresh water entering the Lakes.

Table III. Total catch of groundfish taken in the Bras d'Or Lakes, 1999/2000

Species	Total catch (kg)
Winter flounder	1,509.1
Cod	1,296.1
White hake	195.1
Winter skate	100.3
Windowpane flounder	85.6
Plaice	49.9
White perch	34.9
Longhorn sculpin	19.1
Yellowtail flounder	12.5
Smelt	12.5
Little skate	8.8
Thorny skate	6.9
Cunner	6.4
Shorthorn sculpin	6.2
Sea raven	3.3
Witch flounder	0.6
Gaspareau	0.5
Herring	0.2
Dollarfish	0.1
Silver hake	<0.1
Silverside	<0.1
Mailed sculpin	<0.1
Alligator fish	<0.1
Flying gurnard	<0.1
Atlantic moonfish	<0.1

A total of 46 species of fish has been recorded for the Bras d'Or Lakes (Table IV). Most, like cod, are resident, while others such as mackerel, are regular visitors making seasonal trips into the Lakes. Still others, stray into the Lakes on an irregular basis; these are considered vagrants, individuals that have wandered from their normal range and are present because of usually warm conditions in the Atlantic outside the Lakes. This often occurs in the late summer or early autumn when exotic visitors are transported northwards by the Gulf Stream. Not only do foreign fish species like the sunfish, *Mola mola*; flying gurnard, *Dactylopterus volitans*; and dollarfish, *Poronotus triacanthus* reach Nova Scotia shores in this way, but also other creatures such as sea turtles.

Distribution. There appears to be little difference in the geographical distribution of groundfish as documented by the 1967 and 1999/2000 surveys. Therefore, the distribution of fish in the more densely sampled 1967 survey is provided for illustration (Fig 7 a, b).

Table IV Species list and status of fish reported from the Bras d'Or Lakes.

Common Name	Scientific Name	Status	Reported	Captured
Atlantic cod	*Gadus morhua*	C	B,M,L	T,P
Atlantic moonfish	*Vomer setapinnis*	R (v)	L	T
Atlantic salmon[1]	*Salmo salar*	R	B,L	H
Alligatorfish	*Aspidophoroides monopterygius*	R	B,L	T
American plaice	*Hippoglossoides platessoides*	L	B,M,L	T
Blueback herring	*Alosa aestivalis*	L	D	Tr
Brook trout	*Salvelinus fontinalis*	R	B	H
Cunner	*Tautogolabrus adspersus*	C	B,M,L	T,P
Daubed shanny	*Lumpenus maculatus*	L	L	P
Dollarfish (butterfish)	*Poronotus triacanthus*	R (v)	M,L	T
Eel	*Anguilla rostrata*	L	B,M	T
Eelpout		R	M	T
Flying gurnard	*Dactylopterus volitans*	R (v)	L	T
Fourbeard rockling	*Enchelyopus cimbrius*	C	B,M,L	T,P
Gaspareau (alewife)	*Alosa pseudoharengus*	C (m)	B,M,L	T
Greenland cod[2]	*Gadus ogac*	R	L	H
Haddock	*Melanogrammus aegelfinus*	R	B	T
Herring	*Clupea harengus*	L (m)	B,M,L	T,P
Little skate	*Raja erinacea*	R	L	T
Longhorn sculpin	*Myoxocephalus octodecemspinus*	M	B,L	T,P
Mackerel	*Scomber scombrus*	C (m)	L	P,H
Mailed sculpin	*Triglops murrayi*	R	B,L	T
Ocean pout	*Macrozoarces americanus*	R	B	T
Pipefish	*Sygnathus fuscus*	M	D	B
Pollock	*Pollachius virens*	R	B	T
Rainbow trout[3]	*Salmo gairdneri*	L	B,L	H
Rock gunnel	*Pholis gunnellis*	L	L	P
Sculpins		L	M	T
Sea raven	*Hemitripterus americanus*	L	B,L	T
Shorthorn sculpin	*Myoxocephalus scorpius*	L	B,L	T
Silver hake	*Merluccius bilinearis*	R	L	T
Silverside	*Menidia menidia*	M	L,M	T
Skate		M	B,M	T
Smelt	*Osmerus mordax*	C	B,M,L	T,P
Spiny dogfish	*Squalus acanthius*	R (m)	B	T
Snake blenny	*Lumpenus lumpaetiformis*	L	B,L	P
Sunfish	*Mola mola*	R (v)	B,L	W
Thorny skate	*Raja radiata*	L	L	T
Three-spined stickleback	*Gasterosteus aculeatus*	C	L	T[4]
White hake	*Urophycis tenuis*	M	B,M,L	T,P
White perch	*Roccus americanus*	M (m)	L	T
Windowpane flounder (brill)	*Scophthalmus aquosus*	L	B,M,L	T,P
Winter flounder (blackback)	*Pseudopleuronectes americanus*	C	B,M,L	T,P
Winter skate	*Raja ocellata*	M	L	T
Witch flounder (grey sole)	*Glyptocephalus cynoglossus*	R	M,L	T
Yellowtail flounder	*Limanda ferruginea*	M	B,M,L	T

[1] Wild salmon very rare but farmed salmon occasionally fairly common after escapes from pens.
[2] Taken by longline (4VnSFA), recently in Sept. 2001 by bottom trawl and recorded by Scott (1952)
[3] Stocked in the lakes by NS Department of Fisheries in the past; also farmed and common after escapes.
[4] Often in stomachs of cod.

Status: C - common; M - medium abundance; L - low abundance; R - rare; v - vagrant, m - migratory
Reported: B - Black (1976); M - MacDonald (1967); L - Lambert (present study); D - Denny (2001)
Captured: T - trawl; P - plankton net; B - beach seine; Tr - trap; H - hook&line; W - washed ashore

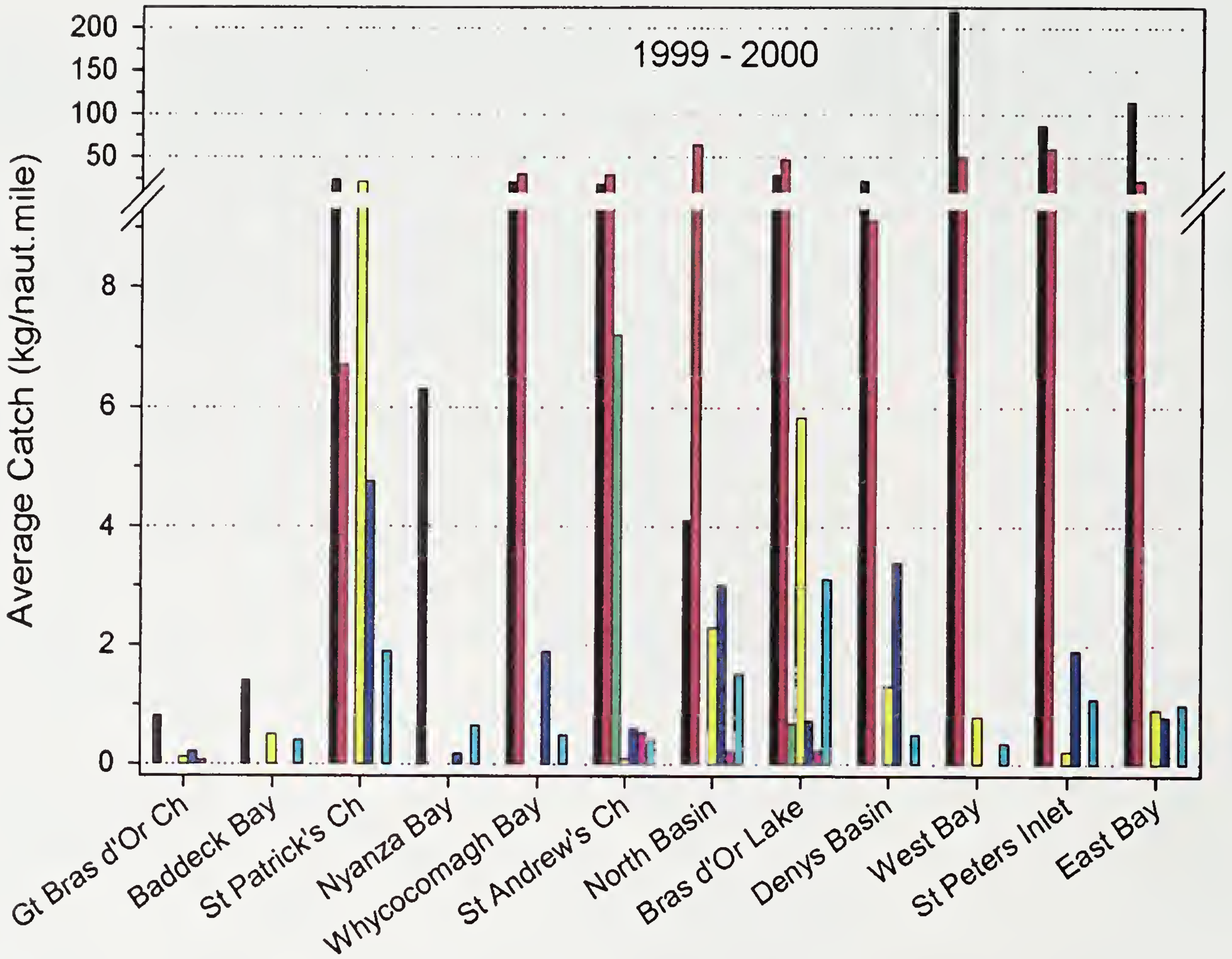

Fig 6 Trawl catch, 1999-2000 by area. Legend for Fig 4 also applies to this Fig..

Of the 8 species shown, the most common, winter flounder, was found at all trawl locations throughout the Lakes (Fig 4-6). Cod were caught at most locations and windowpane flounder, white hake and winter skate, although not plentiful, were also widespread. The most common skate found in the 1999/2000 surveys was the winter skate. Whereas, skates were not specified in earlier surveys, most were likely winter skate, since they were caught in fairly shallow water, where they tend to dominate. Plaice were fairly widespread in 1967, but confined to deep areas of St. Andrew's Channel and Bras d'Or Lake in 1999/2000. In both surveys the distribution of yellowtail flounder was limited to North Basin and a small area of Bras d'Or Lake off Pipers Cove. The distribution of witch flounder was also unchanged and restricted to the deep trench of St. Andrew's Channel.

Depth appeared to be important in determining the distribution of some species, but less so with others (Table V). During the 1999/2000 survey, which fished over the greatest depth range, most winter skate, yellowtail flounder and winter flounder were found in water 21 m or less. The majority of white hake, windowpane flounder and cod were caught between 29 and 45 m and most plaice and witch flounder occurred in water below 150 m. Witch flounder, yellowtail flounder and probably winter skate had the narrowest range of depth distribution, whereas the other major species occurred over many depths. Although the other two surveys fished at shallower depths (1951/1952,10-75m and 1967, 5.5-106 m), and the earlier survey had a seasonal component, similar trends are evident.

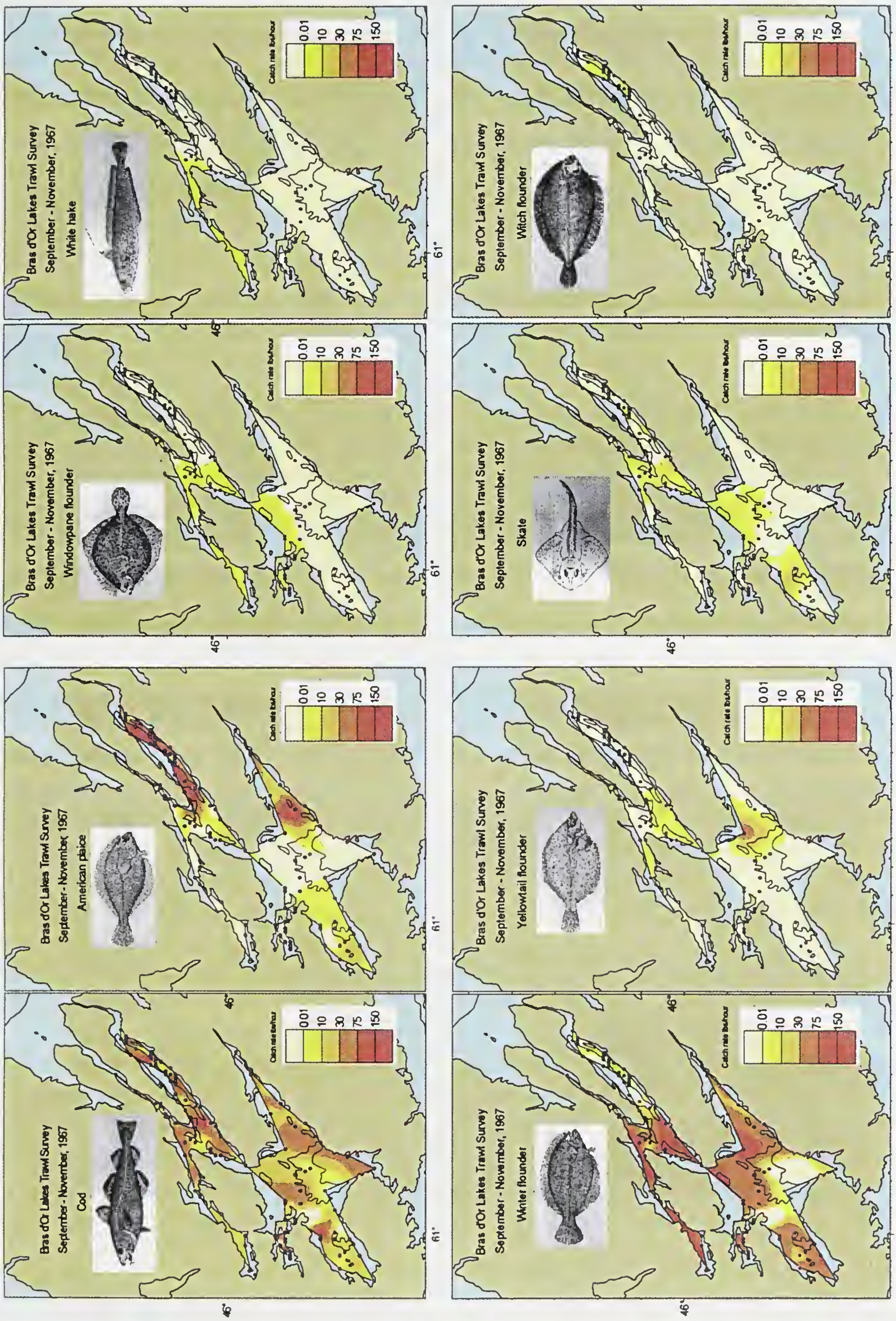
Bras d'Or Lakes Trawl Survey
September - Novemb, 1967
Cod
Bras d'Or Lakes Trawl Survey
September - November, 1967
American plaice
Bras d'Or Lakes Trawl Survey
September - November, 1967
Winter flounder
Bras d'Or Lakes Trawl Survey
September - November, 1967
Yellowtail flounder
Bras d'Or Lakes Trawl Survey
September - November, 1967
Windowpane flounder
Bras d'Or Lakes Trawl Survey
September - November, 1967
White hake
Bras d'Or Lakes Trawl Survey
September - November, 1967
Skate
Bras d'Or Lakes Trawl Survey
September - November, 1967
Witch flounder
Catch rate lbs/hour
0.01
10
30
75
150
46°
61°

Fig 7 Distribution of major fish species from 1967 survey. (a) cod, plaice, winter flounder and yellowtail flounder; (b) windowpane flounder, white hake, skate and witch flounder.

Table V Distribution of selected species by depth (m) by survey. Average value is weighted by catch.

	Minimum		Maximum		WeightedAverage		
Species	99/00	1967	99/00	1967	99/00	1967	51/52
Winter skate*	7	5	27	73	18	25	25
Winter flounder	7	5	260	82	19	26	32
Yellowtail flounder	10	15	27	37	21	23	20
White hake	9	5	134	40	29	22	38
Windowpane flounder	7	5	125	59	31	15	20
Cod	7	5	260	92	45	32	32
Plaice	20	18	263	92	169	53	62
Witch flounder	260	40	260	55	260	51	-

* Assumed to be the predominant species for pre-1999 surveys that specified only "Skate".

Abundance. Some interesting differences are evident in the findings of the trawl surveys conducted during the 3 survey periods. The most noticeable are changes in the relative abundance of species within each survey period (Fig 8). Whereas little change is evident for winter flounder and cod, which dominate the catch in all surveys, American plaice, which in earlier years were common, now form a minor fraction of the total catch. White hake made up a substantial proportion of the catch in 1951/1952, were very scarce in 1967, but increased in 1999/2000 catches. However, the high numbers of hake in 1951/1952 could be due to a geographical bias, since they were seen in later surveys to be more common in the north-west of the Lakes, where most of Black's (1976) fishing sets were located.

In 1999/2000 catches made in the Great Bras d'Or Channel and Baddeck Bay were noticeably lower than other locations (Fig 6). However, catches from the earlier surveys in these same two regions were not substantially lower than in other areas of the Lakes (Fig 4, 5). In 1951/1952 both these areas produced a good catch, dominated by winter flounder. In fact, the Great Bras d'Or Channel, with only 6 tows, yielded almost as many winter flounder as 36 tows off Kempt Head. Baddeck Bay was not sampled in 1967, but tows were made in the Great Bras d'Or Channel and produced an amount of fish slightly less than the average for all sites (Fig 5). In 1999/2000 only one set was made in each of the two areas in question with few fish caught. Bottom temperature at the Baddeck Bay site was high, which would be the reason for the scarcity of cod and possibly other species; whereas, Black's 1951/1952 survey fished during the spring and early summer when bottom temperatures would be more acceptable to cod. The one set in the Great Bras d'Or Channel in 1999 was made just inside the entrance to the Lakes; whereas, in 1951/1952, tows were made along the entire length of the Channel. In 1967, most of the fishing sets were made at the southern end of the Channel close to North Basin (Fig 7). Thus the differences in fish abundance in the Channel between the 1999 and earlier surveys are probably related to differences in tow location, more so than indicative of a general change in abundance within the Channel.

When catch rates are standardised to kg per nautical mile, the data show that, on average, fish seem to be about three times more abundant in 1999/2000 than in1967 (Fig 5, 6; Tables AIII, AIV). Catches in East Bay and West Bay in particular, appear to have increased by about 5-10 times; most of this is appears to be due to an increase in the number of winter flounder. Although the net used by the 1999/2000 survey probably catches more (approx. 1/3 more over a given distance) than that used in the

1967 survey, it seems improbable that such large increases can be attributed to differences in trawl gear alone. A more accurate estimation of catch rates of the more common species was attempted by accounting for differences in gear efficiency (see earlier section on comparison of surveys). For most species, the differences in the recalculated catch rates appear large enough to be real (Table VI). Cod, winter flounder and white hake seem to have increased in abundance and American plaice decreased. Little change was indicated in the case of yellowtail flounder and winter skate.

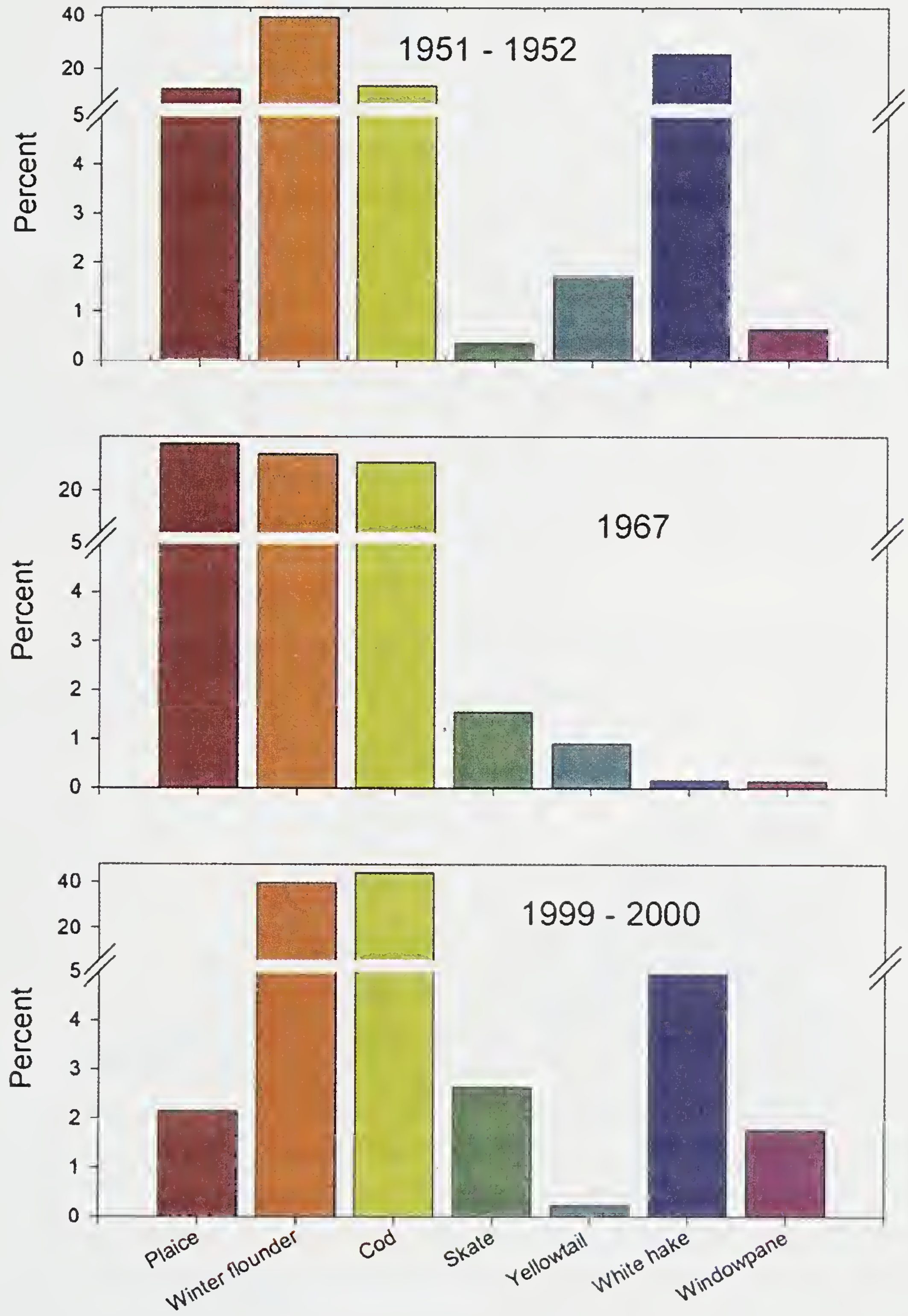

Fig 8 Relative abundance of fish species in the Bras d'Or Lakes between surveys.

Table VI Comparison of catch rate (kg/naut.mile) of some Bras d'Or Lakes' groundfish species between two survey periods. The 1967 data have been multiplied by 1.3 to compensate for gear differences from the 1999/2000 surveys.

Species	1967	1999/2000
Winter flounder	11.9	39.8
Cod	10.0	34.2
Plaice	9.9	1.1
Yellowtail flounder	0.4	0.2
Skate	0.7	1.5
White hake	0.1	3.5

Length frequency. In 1999/2000, fish lengths were measured and length-frequency plots constructed for 6 of the most abundant species (> 95% of total biomass caught). Length data were segregated by year when abundance warranted it, and combined when numbers were too few (Fig 9a-e). Data for fish from Sydney Bight to the Gulf of Maine (Table VII) from Bigelow and Shroeder (1953), Beacham (1982 and 1983a,b), Leim and Scott (1966), and O'Brien *et al.* (1993) allow interpretation of the information provided in Fig 9. Assuming that Bras d'Or Lakes fish do not differ substantially from those within the geographical range of Table VII, only cod, winter flounder and windowpane flounder had clear representation as mature adults, juveniles and young-of-the-year (0-group). Very few of the white hake could be considered mature as only about six of the 501 collected were 40 cm or greater in length. Most of the hake were juveniles with a few 0-group taken in 1999. All of the plaice were probably mature adults. Yellowtail flounder were scarce and mostly adults with a few juveniles.

Table VII Threshold lengths at different life stages for selected species.

Species	Length at 1 year (cm)	Length at maturity (cm)
Cod	10 - 15	30 - 40
Winter flounder	10 - 15	25 - 30
White hake	15 - 20	40 - 50
Windowpane flounder	10 - 12	22 - 25
Yellowtail flounder	12 - 14	25 - 30
Plaice	7 - 8	20 - 40

Clear growth patterns are present in the cod length frequency plots, as year-class modes can be traced from one year to the next. 0-group cod, about 7 months old at the time of survey if spawned in early March, appear as a mode at 8 cm in 1999 (Fig 9a). The year 2000 plot shows this group (now 1 year and 7 months old) as a second mode at about 18 cm. The number of 0-group fish was about three times greater in 1999 (1999 year-class) than in 2000 implying that more young cod were born in the spring of 1999 (assuming juvenile survival was the same in both years). In comparison to 2000, few cod around 18 cm were caught in 1999. This suggests that relatively few cod were hatched in 1998, unless of course, there was high mortality of yearling cod sometime during the year following spawning. Thus it appears the 1999 year-class was better than either of the year before or the year after.

During the recent surveys, and in particular 1999, the number of small white hake was striking Fig 9d. Length frequency data indicate an interesting geographical trend in size. The average length of hake increases from 14.4 cm in the Great Bras d'Or Channel, to 23.5 cm within areas north of the Barra Strait, to 26.8 cm south of the Strait (Table VIII).

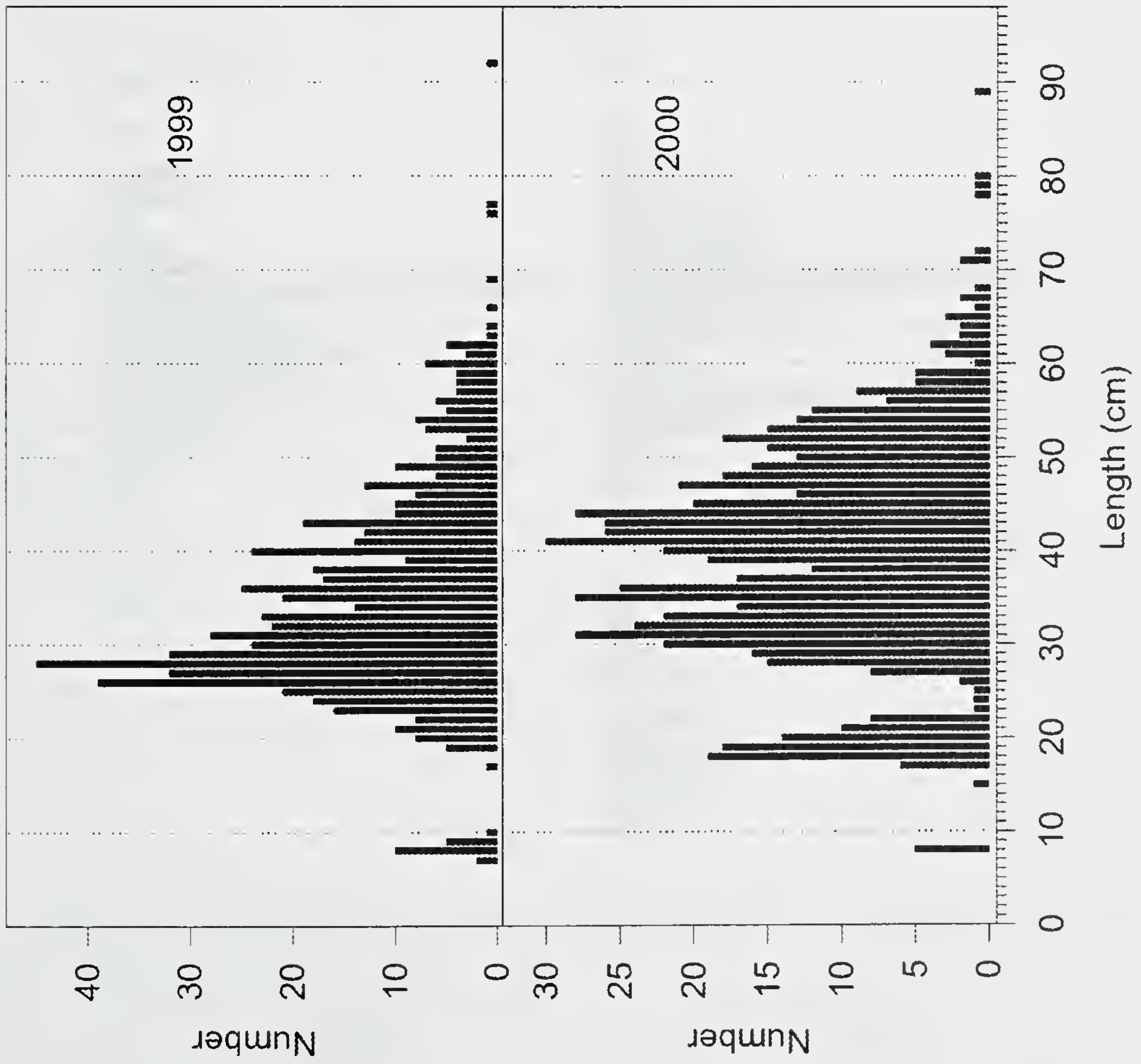

Fig 9a

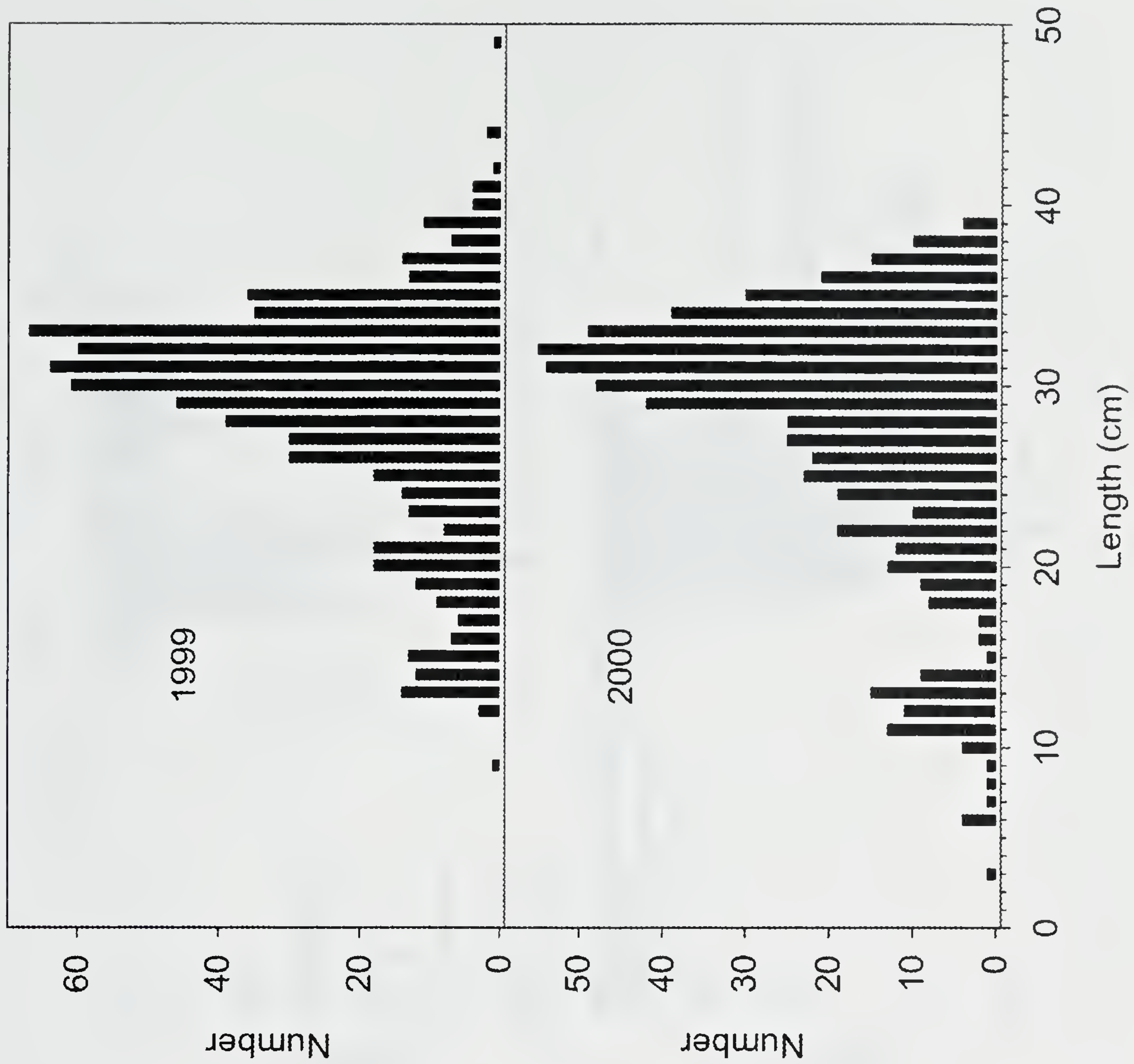

Fig 9b

Fig 9 Length frequencies of selected Bras d'Or Lakes groundfish from trawl samples taken in 1999 and 2000; (a) cod, (b) winter flounder, (c) windowpane flounder, (d) white hake, (e) American plaice and yellowtail flounder [data combined for 1999 and 2000]

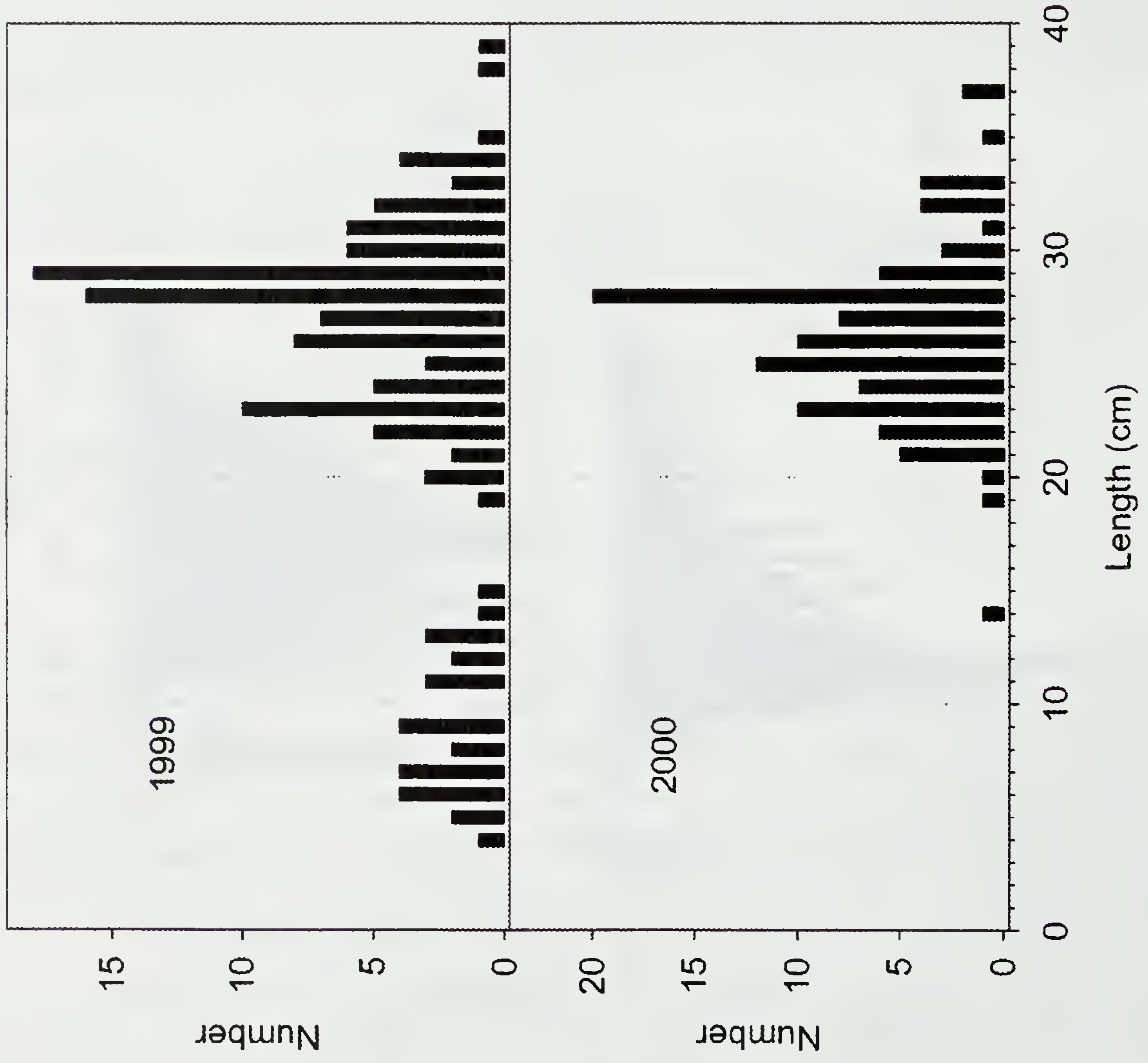

Fig 9c

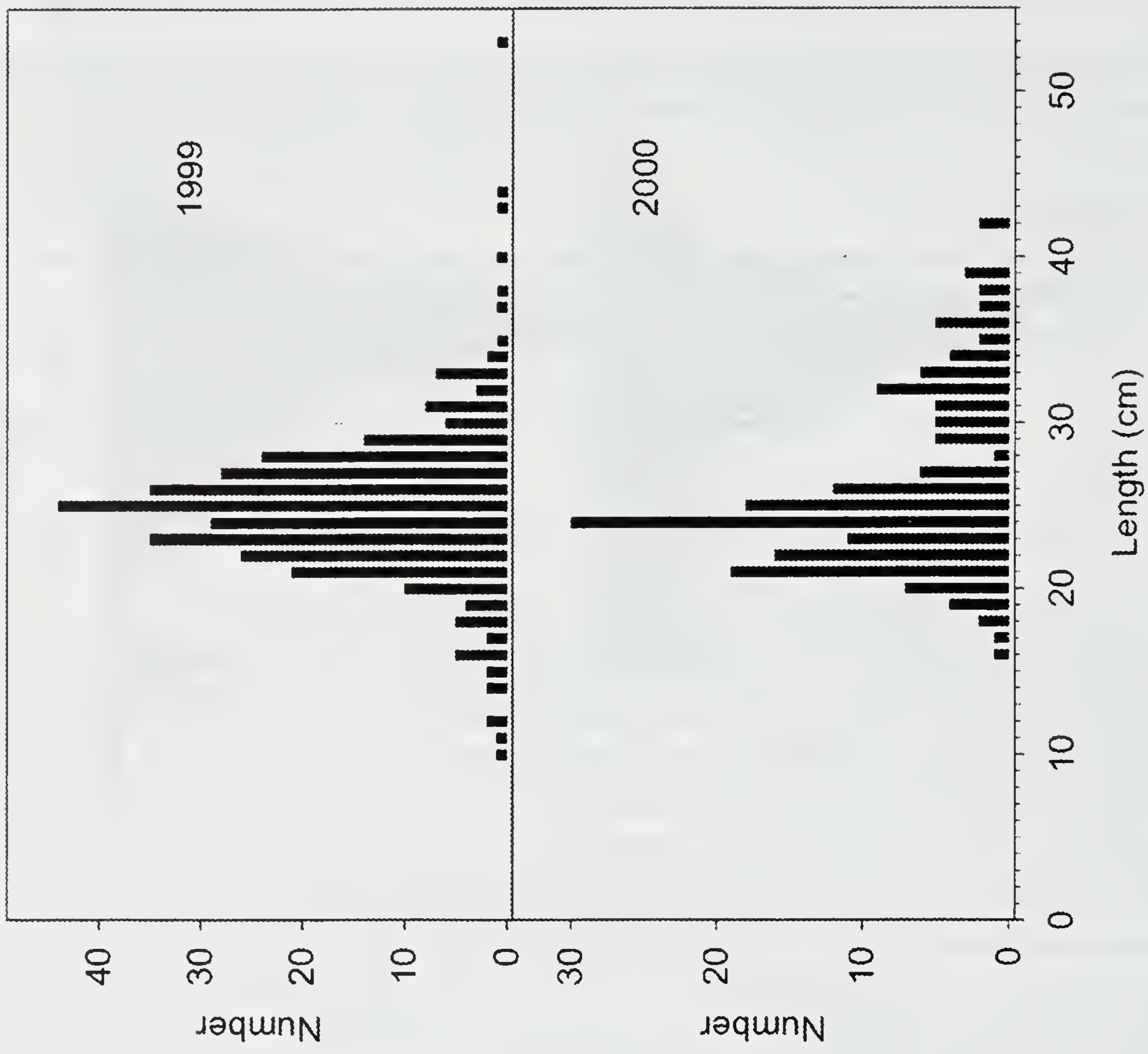

Fig 9d

Fig 9 cont'd

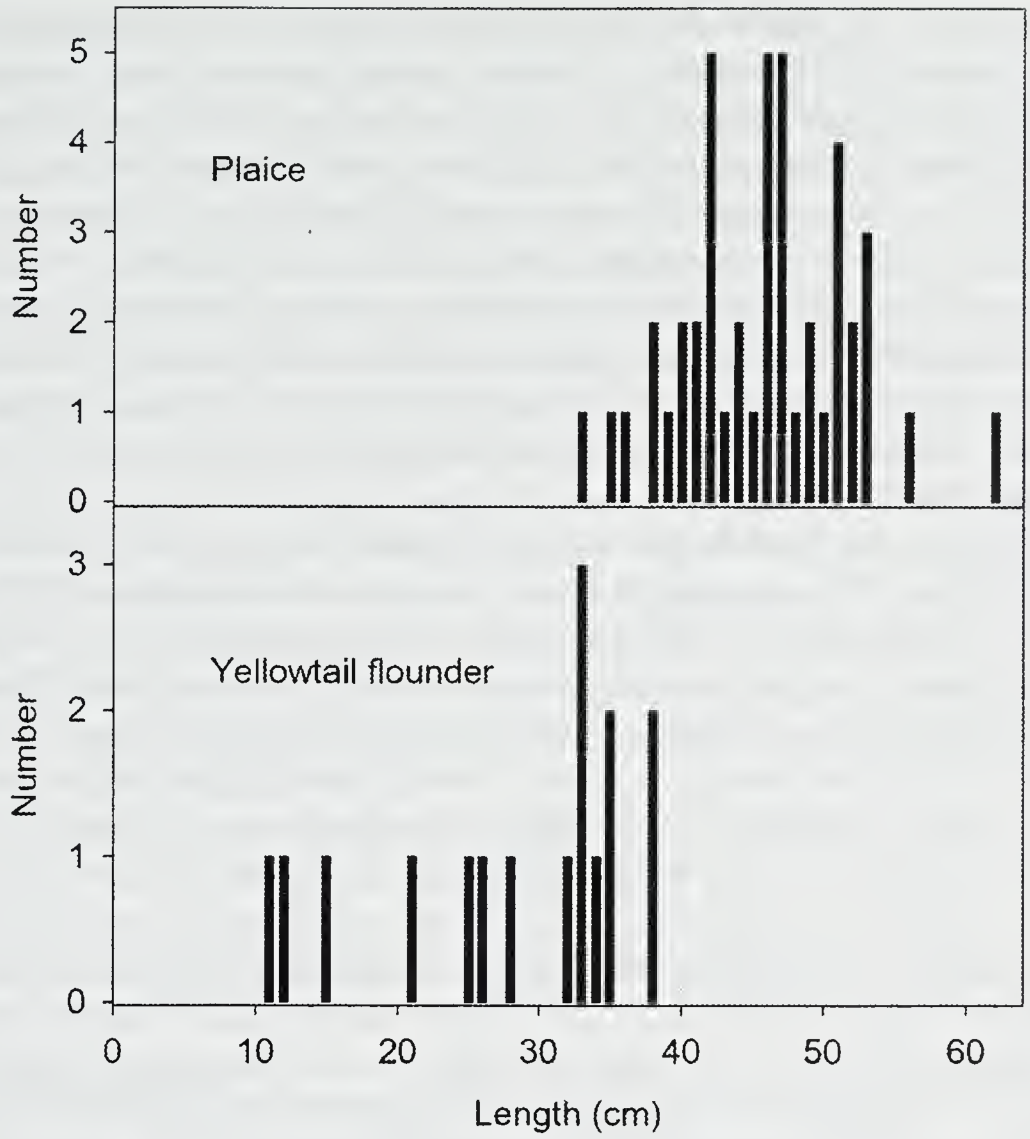

Fig 9e

Fig 9 cont'd

Table VIII Weighted average length of white hake by area of the Bras d'Or Lakes, 1999-2000.

Location	Wt. Average length (cm)
Great Bras d'Or Channel	14.4
Baddeck Bay	21.8
St. Andrew's Channel	23.5
Entrance Denys Basin	23.7
St. Patrick's Channel	23.9
North Basin	24.9
St. Peter's Inlet	25.3
East Bay	26.8
Bras d'Or Lake	28.9
West Bay	29.3

Cod - The case for resident populations. Are the cod in the Bras d'Or Lakes part of the Sydney Bight cod population or are they a separate stock? Certainly many cod in the Lakes look different from Sydney Bight cod, often having a different colouration. However, colour is variable within any cod population. Many Bras d'Or Lake cod are heavily infested by a parasitic worm, often to the extent they appear emaciated. Unfortunately, as with colouration, there is too much variability in this characteristic for it to be a reliable indicator of population affinity. More convincing are results from plankton sampling which reveal that cod spawn in the Bras d'Or Lakes. This spawning, most of which occurs in St. Andrew's Channel and East Bay, is at least a month earlier than in adjacent Sydney Bight, where cod spawn in late April and May, suggesting that the cod in the Lakes are a different stock. This was confirmed by studies that showed distinct genetic differences between Bras d'Or Lakes and Scotian Shelf cod (Pogson *et al.*, 2001). In addition, laboratory testing revealed physiological differences between Lakes cod and their Scotian Shelf counterparts (Nelson et al, 1994 & 1996). In these tests, cod were made to swim against a current in a 'swim tunnel' while their blood chemistry was monitored. The temperature and salinity of the water circulating in this tunnel were then varied and the length of time until the fish tired was measured. The Bras d'Or Lakes cod were found to be more adaptable to changing conditions than were their 'open-ocean' cousins.

Evidence in the form of parasite prevalence suggests strongly that another distinct stock of cod resides in Whycocomagh Bay. Many cod in the Bras d'Or Lakes are heavily infested with the sealworm *(Pseudoterranova decipiens* Krabbe). However, the cod inhabiting Whycocomagh Bay harbour very few of these parasites. Black (1976) quantified the incidence of worms in cod at 3 locations (Table IX); the lower rates of worm infestation in Whycocomagh are clear. Only 10% to 20% of young cod carried worms despite the fact that Whycocomagh Bay is adjacent to St. Patrick's Channel where over 80 % of young cod were infested (Scott and Black, 1960).

Table IX Average number of *Pseudoterranova decipiens* per cod at three locations in the Bras d'Or Lakes (Black, 1976).

	Baddeck Bay		Kempt Head		Whycocomagh Bay	
Age (y)	1950	1951	1950	1951	1950	1951
1	2.3	3.1	5.4	2.5	0.1	0.1
2	11.0	9.9	8.3	8.9	0.3	0.3
3	9.7	17.7	16.0	12.8	0.0	0.3
4	11.9	13.9	14.6	16.2	0.5	0.4
5	15.2	20.3	16.8	21.5	1.3	1.7
6	31.4	26.2		27.9	1.3	2.0
7	34.1	30.1		37.9	4.3	3.2

The worm has a complex life cycle which requires a number of hosts. The adult worm resides in the intestines of the seal and its eggs are shed along with the faeces of the seal. Grey seals (*Halichoerus grypus*) are heavily infested, harbour seals (*Phoca vitulina*) carry much lower worm burdens, and harp seals (*Phoca groenlandia*) are rarely infested (Brattey and Stobo, 1990). The microscopic eggs (approx. 0.04 mm diameter) settle to the bottom and hatch into tiny worm-like larvae about 0.2 mm in length (Bratty, 1990). The larvae attach themselves by their tails to the substrate where their 'wiggling' motion attracts small benthic copepods (Fig 2) which consume the larval parasite. Within the body cavity of the copepod, the parasite grows to about 0.5 mm at which size it is too small to be able to infect a fish. Further growth occurs after transmission to larger invertebrates which prey on the copepod. The hosts at this stage include amphipods, mysids, sand shrimps, nudibranchs (sea slugs) and polychaete worms (McLelland, 1990). The larval worm grows to 2 mm or more within these larger hosts at which point it is capable of surviving the digestive process of a fish and penetrating the wall of its intestine (McLelland *et al.*, 1983). The parasite can be transmitted to a wide range of fish; some such as smelts, pouts, sculpins and flounders, which eat infected invertebrates and others, such as cod and white hake, which consume both invertebrates and other infected fish (McLelland *et al.* 1990). Thus the transmission path of *P. decipiens* through successive hosts is not simple and direct; it is a network of interconnecting paths leading to a myriad of alternate hosts. Successively larger hosts allow the larval parasite to grow until finally, when its intermediate fish host falls prey to a seal, it is large enough to establish residence in the stomach and digestive tract of the seal where it grows to sexual maturity.

It is uncertain whether the number of seals in the Bras d'Or Lakes relative to numbers in the Atlantic coastal region outside the Lakes is high or low. Scott and Black (1960) showed that both harbour seals and grey seals in the Bras d'Or Lakes were carriers of adult *P. decipiens* (the average number in their stomachs was 250 and 1500, respectively). They report that seals frequent the Lakes in winter but are scarce in the summer; highest reported sitings were between Baddeck Bay and Grand Narrows. It is clear that seals in the Lakes have a greater worm load than those outside. In a summary which compares a number of seal investigations, Brattey and Stobo (1990) indicated that 3 grey seals that were autopsied by Scott and Fisher (1958) had an average worm load 5 times greater than seals from eastern Cape Breton outside the Lakes. The mean numbers of adult and larval parasites found in these seals in the Lake were 169 and 2727, respectively.

A distinguishing feature of Whycocomagh Bay is the low level of oxygen in deep basins at each end of the Bay; the western one being completely anoxic (Petrie and Bugden, 2002; Strain and Yeats, 2002). Cod avoid these areas of low oxygen and aggregate at intermediate and shallow depths within the Bay. Due to this lack of oxygen over a large area of the bottom of the Bay, benthic organisms other than some microorganisms could not survive. Thus many of the intermediate invertebrate hosts of the cod worm such as marine worms, amphipods and mysid shrimps would be scarce or absent. Scott and Black (1960) have reported low abundance of mysids in Whycocomagh Bay. In the absence of intermediate invertebrate hosts, the parasite would not be able to complete its life cycle. Furthermore, Scott and Black (1960) report that seals were rarely seen in Whycocomagh Bay. Therefore, the low level of parasites seen in the cod of the Bay may be due to both the scarcity of primary (seals) and intermediate (benthic invertebrate) hosts. It follows that there must be little movement of cod out of Whycocomagh Bay, and conversely, few fish can be moving into the Bay from St. Patrick's Channel where infestations are high. Possibly this is due to the restricted passageway at Little Narrows, which may discourage the movement of cod between the Bay and St. Patrick's Channel (Black, 1976).

Cod in many parts of the north Atlantic are known to undergo extensive migrations related to feeding, spawning and overwintering. The cod of the Gulf of St Lawrence spend about half the year inside the Gulf and the remainder outside in Sydney Bight. After spawning in the Gulf during June, they feed throughout the summer before forming large aggregations in October prior to moving east to deep water in Cabot Strait off Sydney Bight to avoid subzero water temperatures that are prevalent in many areas of the Gulf of St. Lawrence during winter. In late April and May, the cod return to the Gulf to spawn and begin the cycle anew. Other cod stocks on the northeast coast of Nova Scotia, including the resident Sydney Bight stock, also undergo similar migrations, but to a much lesser extent. They inhabit coastal waters during the summer months but then move to deeper, offshore waters during the winter to avoid cold water on the shallow coastal banks.

What of the cod in the Bras d'Or Lakes? Although most evidence seems to indicate that most cod in the Lakes do not venture into Sydney Bight, it is largely circumstantial and qualitative. As mentioned previously, differences in appearance and parasite loads suggest exchange between the Lakes and the Bight is limited, but these are unreliable indicators. Tagging, the only sure way of determining movement of fish, started in 2000 when about 1000 cod were tagged at various locations throughout the Lakes. By the autumn of 2001, 12 tags had been recovered; not enough to make any firm conclusions, but nevertheless, suggestive. The recaptured cod were tagged in St. Patrick's Channel between Baddeck and Nyanza during May in water less than 10 m deep and recovered during the winter by the 4VnSFA longliner in St. Andrew's Channel in water greater than 100 m deep. Contrary to Black's (1976) suggestion, this suggests that these cod, like their cousins in Sydney Bight, move to deeper, relatively warm water to overwinter within the Lakes (water of 2 to 4° C, as opposed to 0° C and lower in the shallows). No Lakes tagged cod have yet been recaptured in Sydney Bight.

Discussion

Zoogeography. The animals that inhabit Nova Scotia's boreal region can be broadly divided into two groups. One group, by far the larger, is restricted to the temperatures normally experienced in this region; the smaller group can tolerate a much wider range of temperatures and can be found from temperate regions to the southern boundary of the Arctic zone. The first group comprises true boreal animals as well as some transitional zone (Arctic-boreal) animals. The boreal component includes cod, white hake, haddock, pollock, herring, longhorn sculpin, sea raven, cunner, rock gunnel and eelpout; Arctic-boreal representatives include alligatorfish and radiated shanny. Gaspareau and winter flounder are examples of the second group of temperature tolerant fish species. All of the above species have been reported from the Lakes.

Another two groups of animals distinguish the Bras d'Or Lakes from the rest of coastal Nova Scotia. They are isolated from their main centres of distribution and are restricted to narrow ranges of temperature. Surprisingly, one set of these isolated species are Arctic and the other are warm water temperate creatures more commonly found off the coast of Virginia (hence they are sometimes referred to as "Virginian enclave" species). Both groups are remnants of populations that were common at some point during the past geologic history of the Bras d'Or Lakes when climate ranged between distinctly Arctic to warmer than it is today. The Arctic animals colonised the Lakes as glaciers retreated after the last ice age about 10,000 years ago. Thereafter, the earth's climate began to warm until, until between 4,000 and 7,000 years ago, global temperatures were 2.0°C warmer than today. During this period, called the climatic optimum, warm temperate species invaded the Lakes.

The Arctic species continue to exist in the cold depths of St. Andrew's Channel, the North Basin and some of the deeper portions of the Bras d'Or Lake, where temperatures do not vary much above 0° C throughout the year (Petrie and Bugden, 2002). Several taxonomic groups are represented; the copepod, *Microcalanus pusillus (Shih et al, 1988)*; the mysid shrimp, *Mysis oculata* (Black, 1958); polychaete worms, *Clymenura polaris, Sabellides borealis* and *Lysippe labiata* (Fournier and Pocklington, 1984); and foraminifera, *Eggerella advena* and *Rheophax arctica* (Vilks, 1967). Relict populations at the other end of the climatic scale are species that are adapted to warm water or require higher temperatures to reproduce successfully. The oyster, *Crassostrea virginica* requires warm temperatures for its gonads to develop properly and temperatures in excess of 20° C to trigger spawning. Similarly, it is thought that the windowpane flounder, *Scophthalmus aquosus* requires warm water to breed properly (Bigelow and Shroeder, 1953). Other examples of isolated warm-water enclave species in the Lakes, are the polychaete worms *Euchone elegans, Polydora quadrilobata*, and *Myriochele heeri* (Fournier and Pocklington, 1984).

Biodiversity The wide range of habitats available within the Bras d'Or Lakes system allows for a corresponding diversity of species. The greatest number of species were collected in St. Andrew's Channel, the North Basin and the Great Bras d'Or Channel (Table X). The first two areas have the greatest range of depth, temperature and salinity and the Great Bras d'Or Channel is a transition zone between the outside Atlantic populations and those of the Lakes. North Basin has the highest overall ranking for species diversity (Table XI) and St. Andrew's and Great Bras d'Or Channels were second. Nyanza Bay, Baddeck Bay and St. Peter's Inlet rank low, but none of these areas is fully represented in taxonomic groups due to incomplete sampling of the Lakes by some surveys, so their rankings cannot be directly compared to the fully sampled areas. Certainly though, for those groups of organisms where they do have representation, they do not rank particularly high, with the exception of Baddeck Bay, where Black (1976) recorded his second highest number of fish species. Of the 4 areas that are fully represented, St. Patrick's Channel has the poorest variety of species, although Whycocomagh Bay, which was not sampled for copepods, is probably lower due to prevalent low oxygen at depth and low salinity near the surface (Petrie and Bugden, 2002; Strain and Yeats, 2002).

Table X Number of Species by Area.

Organisms	GBC	BB	NyB	StPC	Why	StAC	NB	BDL	WB	StPI	DB	EB
Foraminifera	19	9	8	11	9	14	16	16	11	-	11	15
Algae	26	18	20	19	23	26	30	20	20	19	21	20
Polychaetes	48	-	-	16	16	40	27	38	-	-	-	-
Copepods	10	-	-	7	-	14	10	10	-	-	-	-
Fish (1950-1)	10	16	-	10	11	16	19	-	-	-	-	-
Fish (1967)	15	-	-	13	6	16	17	16	12	-	15	9
Fish (1999-0)	10	6	6	12	5	11	17	12	6	8	8	8
Total	138	49	34	88	70	137	136	112	49	27	55	52
Average	19.7	12.3	11.3	12.6	11.6	19.6	19.4	18.7	12.2	13.5	13.8	13

GBC - Great Bras d'Or Channel; BB - Baddeck Bay; NyB - Nyanza Bay; StPC - St. Patrick's Channel; Why - Whycocomagh Bay; StAC - St. Andrew's Channel; NB - North Basin; BDL - Bras d'Or Lake; WB - West Bay; StPI - St. Peter's Inlet; DB - Denys Basin; EB - East Bay.

Fournier and Pocklington (1984) did not distinguish between St. Patrick's Channel and Whycocomagh Bay so the same values are assigned to each area in Tables XI and XII.

Table XI Ranked Species Totals by Area.

Organisms	GBC	BB	NyB	StPC	Why	StAC	NB	BDL	WB	StPI	DB	EB
Foraminifera	1	9	11	6	9	5	2	2	6	-	6	4
Algae	2	12	5	10	4	2	1	5	5	10	9	5
Polychaetes	1	-	-	5	5	2	4	3	-	-	-	-
Copepods	2	-	-	5	-	1	2	2	-	-	-	-
Fish(1950-1)	4	2	-	4	5	2	1	-	-	-	-	-
Fish(1967)	4	-	-	6	9	2	1	2	7	-	4	8
Fish(1999-0)	5	9	9	2	12	4	1	2	9	6	6	6
Overall	2	10	12	5	9	2	1	4	8	10	7	6

Column headings as in Table X.

Abundance and distribution The quantity of animals found in the catch of a trawl net may reflect abundance, but may not because of sampling efficiency. Some bottom dwelling fish such as, eel-pout, which inhabit burrows in soft, muddy bottoms are normally passed over by the net; four-beard rockling, which, as plankton samples show are common, live in cavities under rocks, where they are also not vulnerable to the net. Rocky bottoms, which tear the net, are avoided when fishing, so any species preferring this type of habitat will be undersampled. Real changes in abundance of fish species, which are reflected in trawl catches, could be caused by a number of different factors ranging from ocean climate change to fishing pressures both within and outside the Lakes. Some species of fish do not appear to spawn within the Lakes, or at least not to the extent that self-sustaining populations can be established; therefore, their presence in the Bras d'Or is dependent on exchange with the ocean. In this case, changes in abundance may merely reflect changes on a larger scale in adjacent Sydney Bight. Haddock and pollock for example, were noted in earlier trawl surveys but not caught in the 1999/2000 survey. In Sydney Bight, from 1994 to 1998, the 4Vn Sentinel Survey caught 567 kg of haddock and 134 kg of pollock, compared to 400 tonnes of cod and 32 tonnes of American plaice. From the middle 1980s, haddock and pollock abundance decreased off north-east Nova Scotia probably because of fishing pressure, but for haddock, also because of a widespread decade long decrease in bottom temperatures in the area (Drinkwater et. al., 1999). Haddock, which had been rare in Sydney Bight are beginning to reappear perhaps due to a recent warming trend in bottom temperatures (Drinkwater *et al.*, 1999). Possibly in time, they will reappear in the Lake system if stocks rebuild in Sydney Bight. Winter skate are very common both inside and outside the Lakes, with no break in their distribution between the two areas, probably indicating free exchange between Sydney Bight and the Lakes.

Whereas the presence of some species appears to be related to factors external to the Bras d'Or Lakes, the success of species such as herring, cod, winter flounder, plaice, yellowtail flounder, windowpane flounder and witch flounder seems more related to local events within the Lakes. Herring have been seriously depleted due to overfishing in the Lake and that fishery is now closed. Cod, and particularly winter flounder, appear to have increased in abundance since 1967. The closure of the bottom trawl fishery has probably allowed these stocks to rebuild. Plaice and yellowtail flounder are common outside the Lakes in Sydney Bight, therefore, the low numbers in the Bras d'Or would appear to indicate little or no movement between the two areas. Eggs and larvae of these two flatfish appear in plankton samples, but in very small numbers. These could originate with the few mature adults in the Lakes or possibly they may have been transported into the Lakes from Sydney Bight. Fig 9e indicates that juvenile yellowtail are present in the Lakes but there was no evidence of young plaice, as no individuals smaller than 30 cm were caught; thus it would appear there has been little or no recruitment to the plaice population in recent years. In the case of windowpane flounder, however, there can be no doubt that this species is a self-sustaining population within the Lakes for this species requires water around 20° C to reproduce (Bigelow and Shroeder, 1953) and these temperatures are rarely attained in outside coastal waters. Witch flounder, on the other hand, are found only in deep, cold water at the bottom of St. Andrew's Channel; in Sydney Bight they are common, but well offshore at depths over 100 m. This species was a rare occurrence in the 1967 survey, and is probably even scarcer now since only one individual was caught in the 1999/2000 surveys. Whether this isolated pocket of witch flounder is a result of occasional larvae drifting into the Lakes and settling there, or whether there is a self-sustaining is difficult to say.

White hake appear to have been plentiful in the early 1950s, to have decreased substantially by 1967, and have increased since then. Draggers (bottom trawling) were active until 1992 when they were banned from operating in the Lakes. It is possible this fishing activity may have reduced the numbers of hake during the period represented by the 1967 survey, and that they rebounded after the prohibition on trawling. However, since white hake larvae are extremely rare in plankton samples, it is unlikely that hake spawn in the Lakes; their abundance is probably more dependent on the fortunes of the stock outside the Bras d'Or Lakes. However, there appears to be more to the white hake story. Recall that most of the catch of hake in the Lakes consisted of juvenile fish (Fig 9d), with a trend of increasing size from the entrance inward (Table VIII). This can be interpreted as a "seeding" from Sydney Bight of young hake, which move into the Lakes for the duration of their juvenile stage before moving back out into the Bight as near-mature adults. Possibly, the Bras d'Or Lakes is a nursery area for at least some portion of a white hake stock external to the Lakes. Similarly, in nearby St. Ann's Harbour, high numbers of small white hake, but no adults, have also been taken in an ongoing DFO inshore survey begun in 1991.

Of the fish species within the Bras d'Or Lakes, herring, cod, winter flounder, windowpane flounder, plaice, yellowtail flounder and probably witch flounder appear to be resident; whereas, white hake, winter skate and, in the past, haddock and pollock are more likely part of a continuous distribution with the larger, adjacent coastal area.

Are the Bras d'Or Lakes unique? At first glance the Bras d'Or Lakes, albeit far smaller, may appear similar to other large, more or less enclosed seas, such as the Baltic and Black. All three have been termed brackish, but the Bras d'Or Lakes by far the most salty, would not qualify as brackish according to Ekman's (1953) classification system. Apart from estuarine conditions where rivers enter, the salinity of the Bras d'Or Lakes ranges from about 20 at the surface to about 26 at depth (Krauel, 1976; Petrie and Bugden, 2002). In Ekman's scheme, the threshold salinity between brackish and saltwater is 17 to 20. Thus the Baltic, which is mostly below 10, and with the highest values near the entrance only 15, is brackish. With the exception of deep waters, the Black Sea is mostly below 20 so it is a borderline case. Most of the glacial relicts described are from the Baltic and thus found in clearly brackish water. Arctic relicts from water more salty than 20 are very rare; only one or two have been reported (Ekman 1953). Therefore, the Bras d'Or Lakes with a number of relict species (and not confined to one taxonomic group) is a rarity. If we accept Ekman's definition of brackish, the Bras d'Or Lakes may be the only truly marine body of water that is home to so many glacial relicts. Furthermore, not only are there glacial relicts, but paradoxically also warm water enclave relicts. This must make the Lakes unique.

A better place to undertake marine ecosystem research would be hard to find. In addition to their unique assemblage of organisms and diverse habitats, the Bras d'Or Lakes have a number of other attributes which ideally suit them to marine research. Whereas the low flushing rates of the Lakes could be considered a liability, rendering them highly vulnerable to spills of pollutants, this same characteristic is a boon to biologists interested in the study of life histories of marine organisms. Usually it is very difficult to measure the survival rate of animals in the sea, particularly egg and larval stages, because one can never tell whether decreases in numbers are due to drift out of the study area or to on-site mortality. Plankton patches on the continental shelf can rarely be tracked for more than a few days. The low flushing, combined with the fact that the Lakes contain resident marine populations, provides a unique opportunity for quantitative studies of all stages of the life history of an organism. Throughout the Northwest Atlantic, many cod stocks were decimated in the late 1980s and have failed to recover after ten years or more. Why these stocks are not rebuilding is an open question. A study of the resident cod population in the Bras d'Or Lakes could provide valuable insights into the population dynamics of this species.

As we have seen within the Bras d'Or Lakes, one can find species which normally would be found only by travelling south to Virginia and in the opposite direction north to Baffin Island in the Arctic. Amazingly, over 30° of latitude are represented within distances of less than 10 km in Cape Breton's inland sea. Certainly, as McLachlin and Edelstein (1971) noted, "The great diversity of habitats in the Bras d'Or Lakes presents a unique opportunity for extensive ecological observations."

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Appendix

Table AI Number of sets made by location in three trawl surveys in the Bras d'Or Lakes. Data from Black (1976), MacDonald (1968) and Lambert (this study).

Location	1951-1952	1967	1999-2000
Great Bras d'Or Channel	6	8	1
Baddeck Bay	78	-	1
St. Patrick's Channel	9	6	4
Nyanza Bay	-	-	2
Whycocomagh Bay	42	4	4
St. Andrew's Channel	-	34	5
North Basin	36	17	7
Bras d'Or Lake	-	16	9
Denys Basin	-	11	2
West Bay	-	11	2
St. Peter's Inlet	-	-	2
East Bay	-	8	4
Total	171	115	43

Table AII Mean catch (numbers/tow) of selected species by location in Bras d'Or Lakes. 1951 & 1952 combined (Black, 1976).

Location	Cod	Winter flounder	Window pane flounder	Yellow tail flounder	Plaice	White hake	Skate	Total
Gt. Bras d'Or Chn.	11.3	222.7	-	17.8	-	0.7	0.5	253.0
Baddeck Bay	12.1	43.2	1.3	2.4	1.7	32.6	0.6	93.9
St. Patrick's Chn.	1.8	8.3	0.2	0.1	0.1	0.6	0.1	11.2
Whycocomagh Bay	18.5	13.7	<0.1	<0.1	0.1	1.0	<0.1	33.5
Kempt Head	19.3	46.0	0.2	0.3	58.5	56.1	0.3	180.6
Average	12.6	66.8	0.4	4.1	12.1	18.2	0.3	114.4

Table AIII Mean catch (kg/naut. mile) per set of selected species by location – 1967 survey (MacDonald, 1968). (Note, these data have not been adjusted for gear differences with the 1999/2000 survey.)

Location	Cod	Winter flounder	Window pane flounder	Yellow tail flounder	Plaice	White hake	Skate	Total
Great Bras d'Or Chn.	4.99	14.49	0.09	1.83	0	0.43	1.72	23.91
St. Patrick's Channel	5.02	17.98	0.04	0.33	0	0.54	0.15	24.20
Whycocomagh Bay	1.10	23.77	0.10	0	0	0.02	0	25.35
St. Andrew's Channel	6.77	1.44	0	0.01	20.67	0.01	0.10	29.00
North Basin	8.45	11.45	0.04	0.53	6.20	0.03	1.27	28.13
Bras d'Or Lake	4.40	7.74	0.15	0.42	0.03	0.02	0.30	13.64
Denys Basin	19.45	13.66	0.17	0	0	0.01	0.18	34.11
West Bay	5.20	9.02	0	0	0.88	0	0.86	15.96
East Bay	9.30	12.14	0.03	0	5.59	0	0	27.15
Average of Locations	7.19	12.41	0.07	0.35	3.71	0.12	0.50	24.60
Average of all Sets	7.52	8.98		0.28	7.51	0.07	0.49	

Table AIV Mean catch (kg/naut. mile) per set of selected species by location -1999/2000 surveys.

Location	Cod	Winter flounder	Window pane flounder	Yellow tail flounder	Plaice	White hake	Skate	Total
Great Bras d'Or Chn.	0	0.80	0	0.06	0	0.10	0.20	1.16
Baddeck Bay	0	1.40	0.40	0	0	0.50	0	2.30
St. Patrick's Channel	6.70	20.04	1.89	0	0	21.17	4.76	54.86
Nyanza Bay	0	6.30	0.64	0	0	0.00	0.17	7.11
Whycocomagh Bay	30.60	20.89	0.49	0	0	0	1.88	53.86
St. Andrew's Channel	29.26	18.92	0.41	0.52	7.21	0.08	0.06	57.00
North Basin	64.31	4.11	1.50	0.21	0	2.29	3.00	75.42
Bras d'Or Lake	46.70	29.35	3.11	0.22	0.68	5.82	0.73	86.61
Denys Basin	9.10	22.30	0.50	0	0	1.30	3.40	36.60
West Bay	50.80	218.90	0.35	0	0	0.79	0	270.84
St. Peter's Inlet	60.00	87.20	1.10	0	0	0.20	1.90	150.40
East Bay	21.90	114.80	1.00	0	0	0.92	0.79	139.41
Average of Locations	26.53	45.75	0.95	0.08	0.66	2.76	1.45	78.13
Average of all Sets	34.25	39.77	1.38	0.15	1.08	3.48	1.53	

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LARGE EPIBENTHIC INVERTEBRATES IN THE BRAS D'OR LAKES

M. JOHN TREMBLAY
Invertebrate Fisheries Division, Fisheries and Oceans Canada
Bedford Institute of Oceanography, P.O. Box 1006
Dartmouth, N.S. Canada B2Y4A2

The distribution of large epibenthic invertebrates (lobster and crabs, bivalve molluscs and echinoderms) in the Bras d'Or Lakes is reviewed, and possible limiting factors are identified. The review is based on published and unpublished studies, including recent trawl surveys directed at fish, and trapping studies directed at American lobster *Homarus americanus* and green crab *Carcinus maenas*. The reduced salinities within the Lakes probably limit the distribution of several species (rock crab *Cancer irroratus*, sea scallop *Placopecten magellanicus* and possibly American lobster), particularly during the more sensitive larval period. Lobsters and eastern oysters *Crassostrea virginica* serve to illustrate the multiple factors limiting epibenthic invertebrate distribution within the Bras d'Or Lakes. Lobsters are less abundant within the Bras d'Or Lakes than on the outer coast of Cape Breton Island. Possible reasons are the reduced salinity and limited cobble bottom substrate in the Bras d'Or Lakes, coupled with low food availability and low egg production. Low egg production may be the result of overfishing of lobsters in the past. The life history and physiology of the eastern oyster appears to be well suited to the areas of the Lakes with warm summer temperatures. The oyster populations in the Bras d'Or Lakes are limited by natural predators (e.g. starfish and green crab), competitors (e.g. blue mussel *Mytilus edulis* and *M. trossulus*), and overfishing. The green crab, a new arrival to the Bras d'Or Lakes, will likely have negative effects on bivalves such as oysters, but the overall effect of green crab on the Bras d'Or Lakes food web is difficult to predict. Recent trawl surveys indicate both sea urchins *Strongylocentrotus droebachiensis* and starfish are present in considerable abundance, but little is known about their ecological roles in the Bras d'Or Lakes.

La distribution des grands invertébrés épibenthique (les homards et les crabes, les mollusques bivalves et les échinodermes) dans les lacs du Bras d'Or est examinée et les coefficients possiblement limitatifs sont identifies. La revue est basée sur des études publiées et non-publiées englobant les plus récentes études sur la pêche au chalut dirigées vers les poissons et les études sur la pêche aux casiers dirigées vers les homards américains *Homarus americanus* et les crabes verts *Carcinus maenas*. Salinités réduites dans les lacs du Bras d'Or limitent probablement la distribution de quelques espèces crabes roches *Cancer irroratus*, pétoncle géant *Placopecten magellanicus* et possiblement le homard américain, en particulier, pendent l'époque sensible du larvaire. Les homards et les huîtres de l'Est *Crossostrea virginica* montrent plusieurs facteurs coefficients limitatifs de la distribution des invertébrés épibenthique dan les lacs du Bras d'Or. Les homards sont moins abondants ici que sur la côte extérieure de L'Ile du Cap Breton. Des explications possibles sont la réduction de l'eau saline du pavé rond limite dans le substratum de lacs, ainsi que la pauvre disponibilité de mangé et la production basse des œufs. Cette dernière est peut-être le résultat d'un trop grand prise de homards au passè. L'histoire et la physiologie des huîtres semblent être bien adaptés aux lieux des lacs de Bras d'Or, qui ont des temperatures chaudes dan l'été. La population des huîtres dans les lacs est limitée par des proies natures (ie étoiles de mer et les crabes verts) compétiteurs (ie. Moules bleus *Mytilus edulis* et *M. trossulus*) et une trop grande prise de poissons. Le crabe vert, une arrivée nouvelle dans les lacs du Bras d'Or va sans doute avoir des impacts négatifs sur les bivalues comme les huîtres, mais leurs impacts en general sur la chaîne nutritive est difficile à prédire. Les études les plus recents sur la pêche au chalut montrent qu'il y a un grand nombre d'oursins de mer *Strongylocentrotus droebachiensis* et des étoiles de mer, mais on ne connait pas quel est leur rôle écologique dans les lacs du Bras d'Or.

Introduction

Epibenthic invertebrates live on the surface of the seabed. Most species belong to taxonomic groups such as crustaceans (e.g. lobster *Homarus americanus*, rock crab *Cancer irroratus* and green crab *Carcinus maenas* - Fig 1), bivalve molluscs (e.g. eastern oyster *Crassostrea virginica*, blue mussel *Mytilus edulis* - Fig 1), gastropod molluscs (e.g. whelks, periwinkles) or echinoderms (e.g. sea urchin *Strongylocentrotus droebachiensis,* starfish). The term shellfish is reserved for those groups that are edible, including species such as oysters and lobsters that are of major economic and cultural importance. Infaunal invertebrates live within the sediment and include worms such as polychaetes and nematodes, small crustaceans such as amphipods and isopods, and several lesser known phyla. This paper reviews the limited information available on the distribution and abundance of some of the larger epibenthic invertebrates in the Bras d'Or Lakes. There has been no single comprehensive study of invertebrate distribution within the Lakes, but by drawing from published and unpublished studies, as well as traditional and anecdotal knowledge, it is possible to document some major patterns. To better understand the distribution of some key species, important features of the Bras d'Or Lakes environment are reviewed, together with invertebrate life histories and environmental relationships.

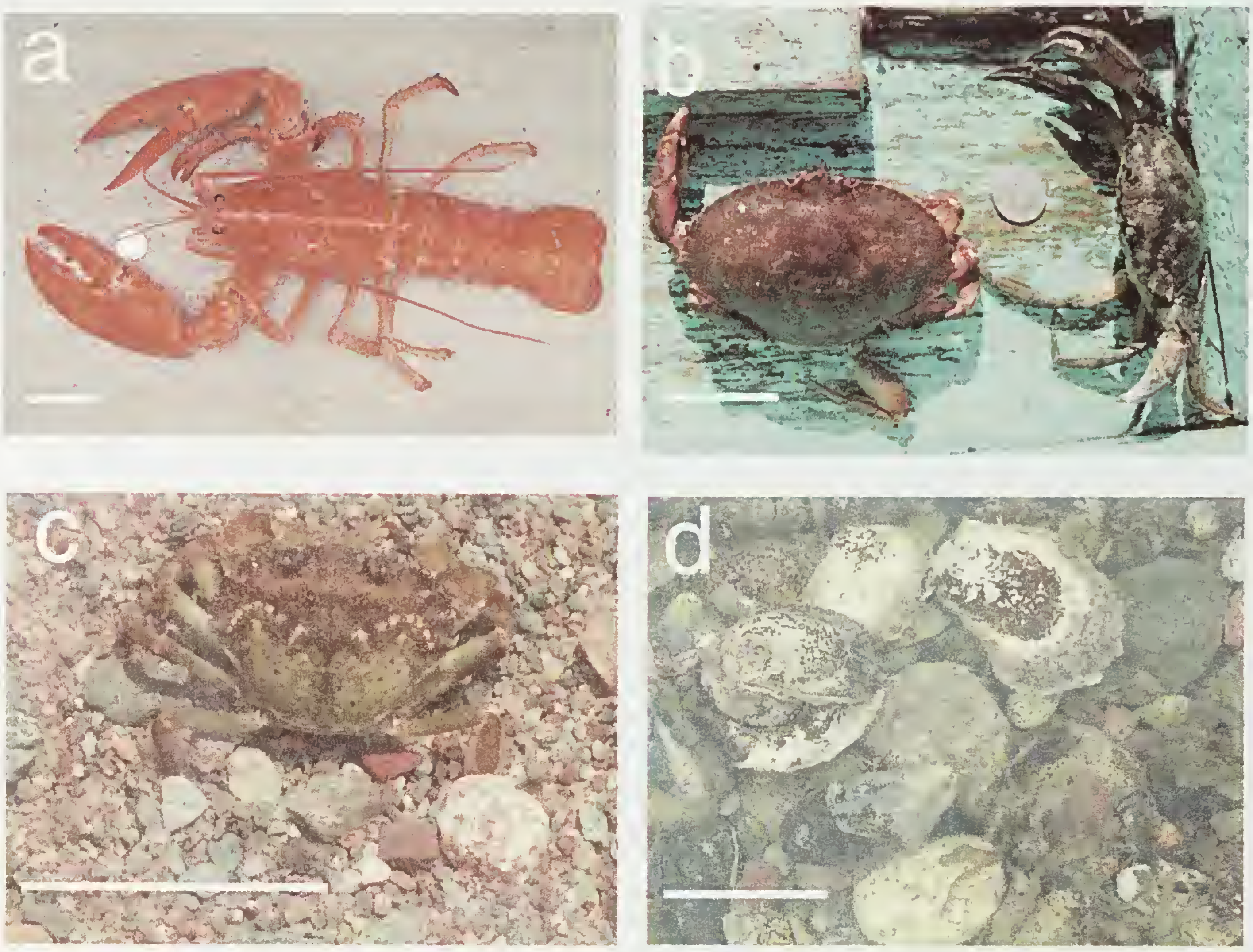

Fig 1 Photographs of some common epibenthic invertebrates found in the Bras d'Or Lakes. (a) A live orange lobster (a colourmorph) trapped in the Great Bras d'Or Channel, (b) male rock and green crabs captured in the same trap, (c) a green crab in a few cm of water off Benacadie Point, Outer East Bay (d) oysters and a blue mussel off Benacadie Point. White scale bar is 5 cm.

The Physical and Biological Setting

Oceanography Key oceanographic features of the Bras d'Or Lakes (Fig 2) relevant to the distribution of epibenthic invertebrates include their semi-enclosed nature and freshwater input, their wide-ranging temperatures, and their low tidal amplitudes

(Petrie and Bugden, 2002). Exchange with the more oceanic waters of Sydney Bight is limited by the narrow and shallow entrances to the Lakes. This limited exchange, coupled with the freshwater input, leads to reduced salinity, which is apparent in plots of salinity frequency for 3 areas within the Lakes, and in Sydney Bight (Fig 3). Salinities decrease with distance from Sydney Bight, with most observations in Bras d'Or Lake between 21 and 23. By comparison salinities in Sydney Bight are typically between 29 and 32 (Fig 3). Throughout the Bras d'Or Lakes salinities are lower in the 0-10 m depth interval than in the 10-50 m depth interval and in the upper metre of the

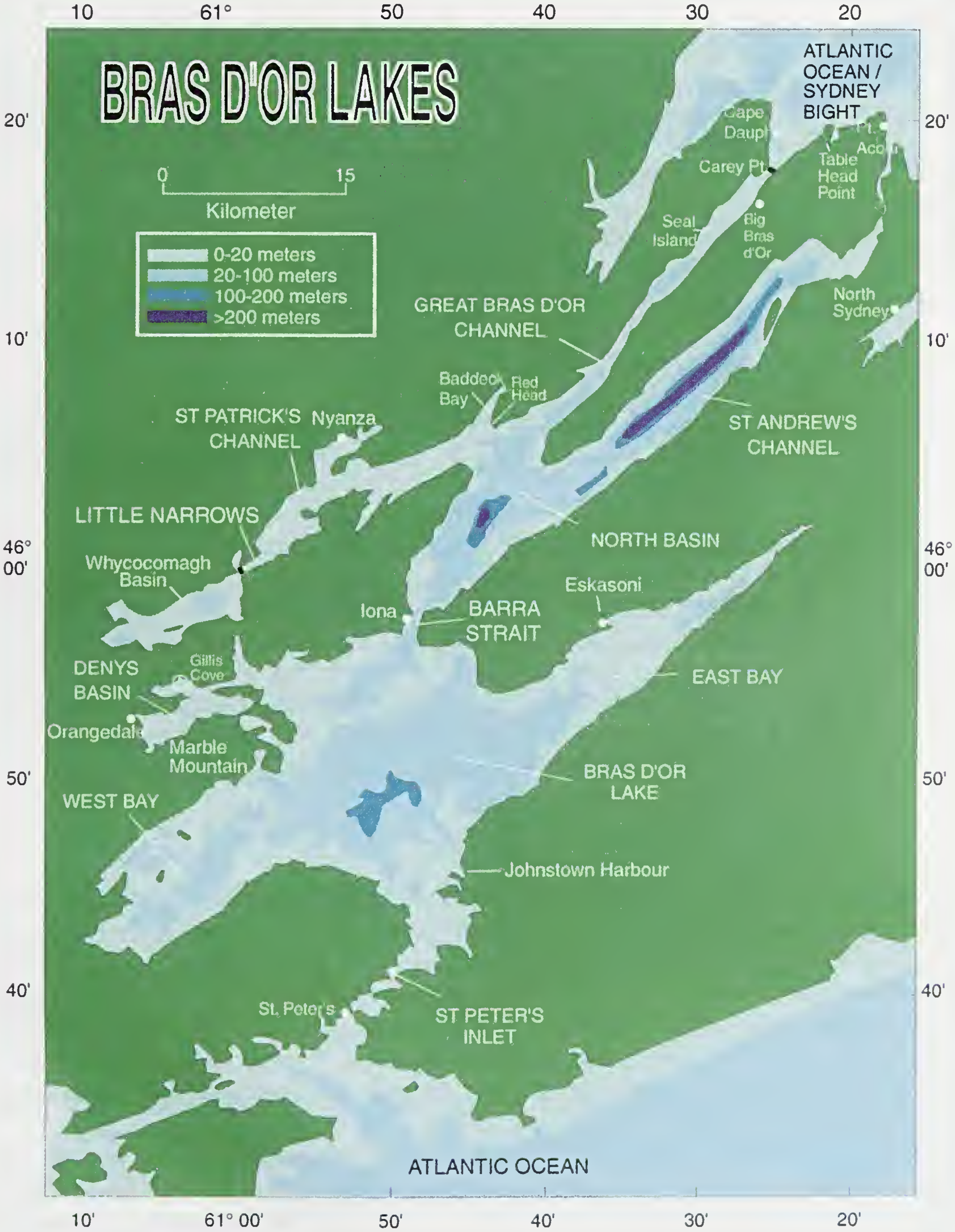

Fig 2 Map of the Bras d'Or Lakes showing place names used in text

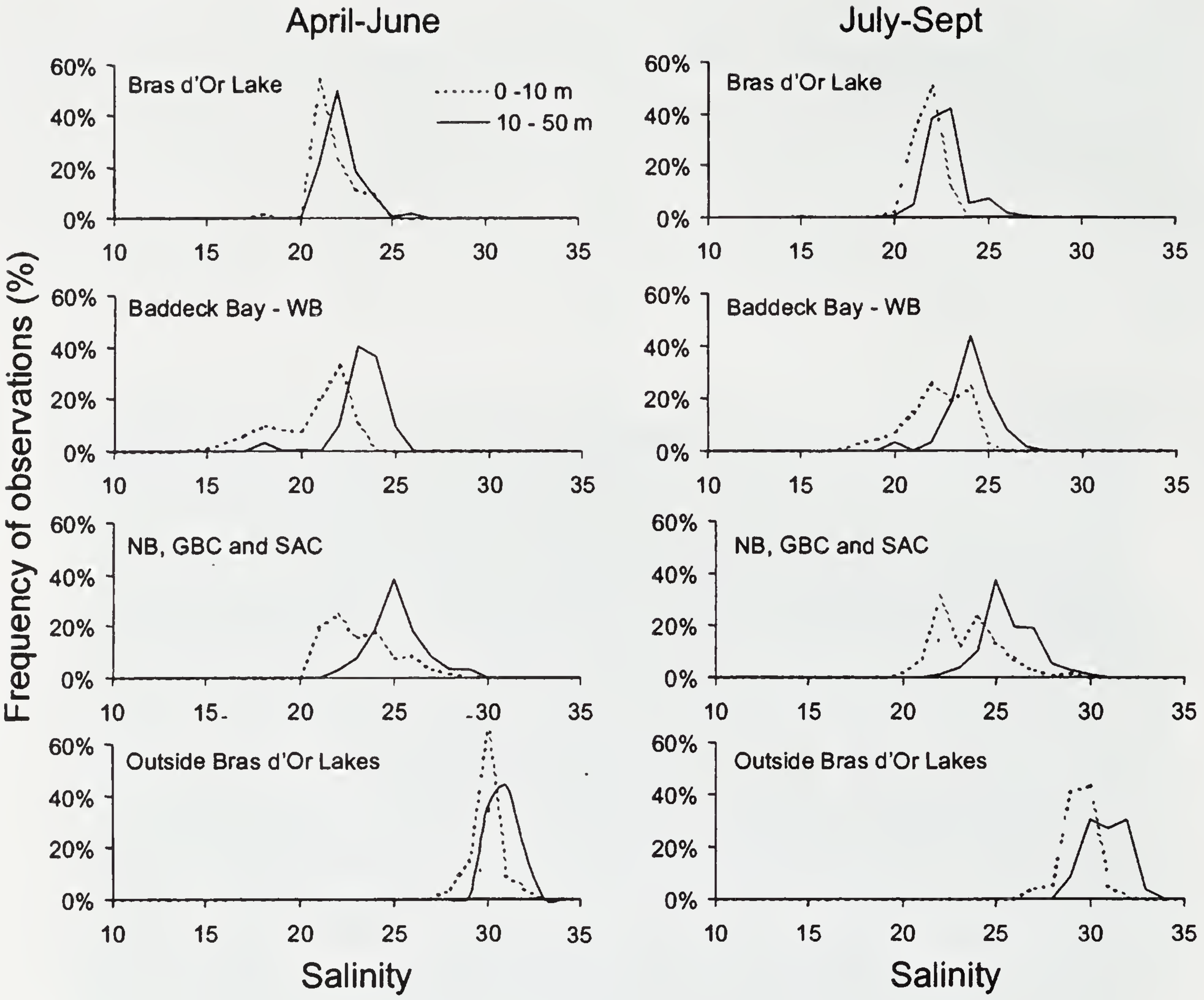

Fig 3 Frequency distribution of salinity measurements taken inside and outside the Bras d'Or Lakes. Oceanic salinities are > 30; freshwater is 0. Data are from April-June and July-Sept. Bras d'Or Lake includes West and East Bays, Baddeck Bay – WB (Whycocomagh Basin) includes Baddeck Bay, St. Patrick's Channel and Wycocomagh Basin; NB, GBC and SAC is North Basin, Great Bras d'Or Channel and Saint Andrew's Channel; Outside Bras d'Or Lakes is the area extending approximately 30 km north of Cape Dauphin and Point Aconi and 60 km to the east.

Wycocomogh and Denys Basins maybe 5 after rainfall (Petrie, 2001). There is also a seasonal difference in salinity, with lower salinities in spring compared to summer.

Bottom temperatures can range from 0°C to more than 20°C in some shallow embayments but at depths greater than 60 m, temperature is below 6°C year-round (Petrie and Bugden, 2002). Ice cover can be extensive in some years. The small tides in the Lakes result in a negligible intertidal zone. In Sydney Bight the difference between low and high tides is 1-2 m, but this is reduced by half in the Great Bras d'Or Channel and to about 10 cm in Bras d'Or Lake.

Bottom type The composition of the epibenthos is strongly affected by bottom type. Vilks (1967) analyzed the sediment obtained in samples from an Ekman dredge (box-type sampler with spring loaded jaws) deployed at some 196 stations throughout the Bras d'Or Lakes. A plot of the frequency of different grain sizes in different parts of the Lakes shows that most sediment is comprised of silt with smaller proportions of sand, gravel and boulder (Fig 4). The boulder category was not what we typically think of as boulders since the minimum size was just 16 mm diameter. The Great Bras d'Or Channel, North Basin and St. Andrew's Channel had a lower percentage of smaller grain sizes than Denys Basin and St. Patrick's Channel. Depth and current were important factors in determining sediment size, since fine sediments rich in organic matter were characteristic of the restricted deep regions of Wycocomagh Bay and St. Andrew's Channel, the relatively shallow but protected regions of St. Patrick's

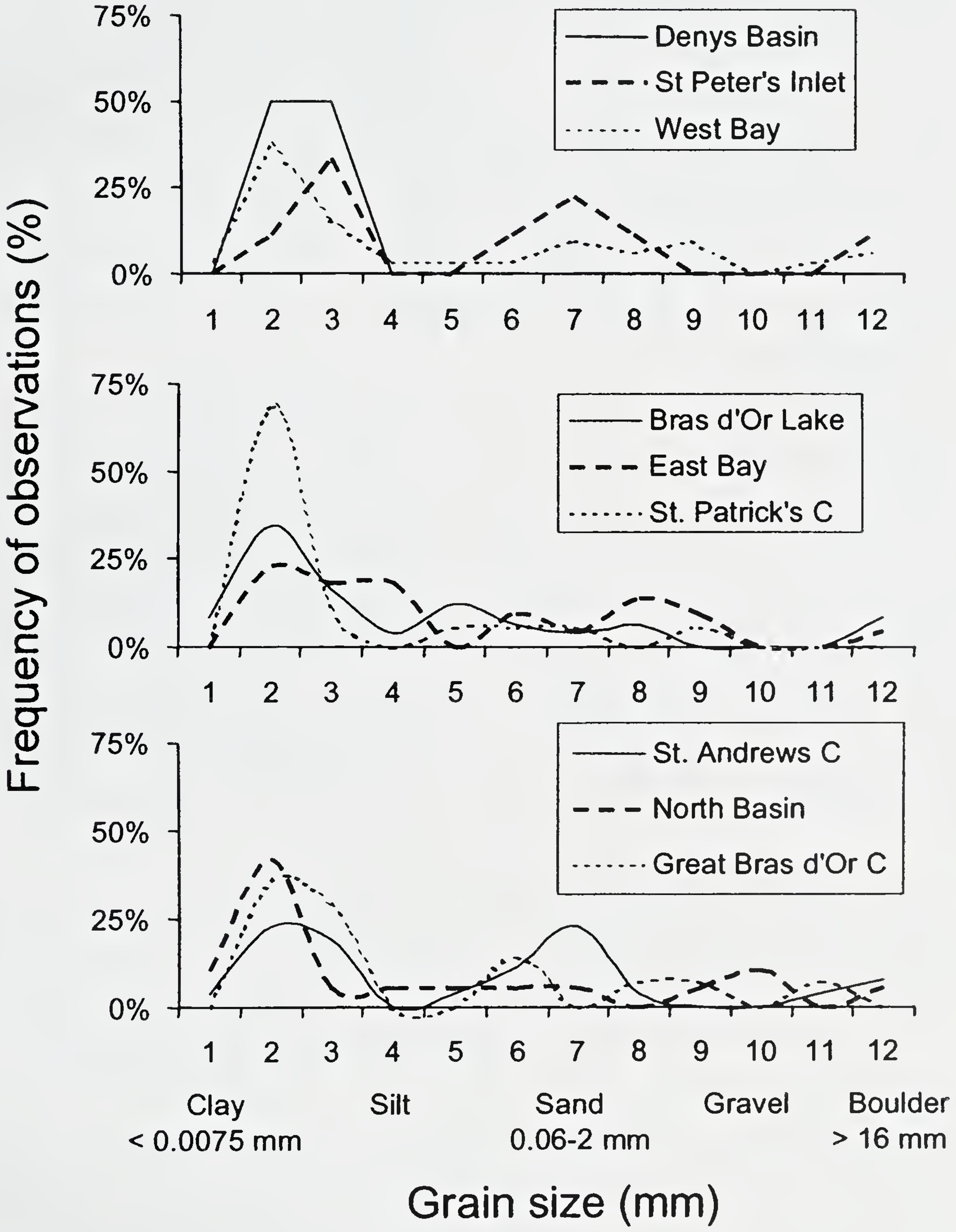

Fig 4 Frequency distribution of grain size measurements from different parts of the Bras d'Or Lakes. Data were obtained with an Ekman dredge sampler by Vilks (1967). The 12 categories from Vilks (1967) are of increasing size corresponding to the different mixtures of clay, silt, sand, gravel and boulder. Some categories (e.g. clay-sand) were combined with adjacent categories if the number of observations was < 3.

Channel, and the central deep areas of Bras d'Or Lake. In the Great Bras d'Or Channel and the more shallow regions of the Lakes, sediments were coarser (Vilks, 1967).

Shoreline Vegetation Different types of shoreline vegetation are associated with different epibenthic communities. A study of the marine flora of the shorelines of Bras d'Or Lakes (McLachlan and Edelstein, 1971) reported that the single most abundant form of shoreline vegetation was eelgrass (*Zostera marina*, a flowering angiosperm - Fig 5a). It was present throughout the Bras d'Or Lakes in silt and mud. Marine algae occupied a narrow band to a depth of 3-4 m. A total of 92 species of marine benthic algae were recorded and McLachlan and Edelstein (1971) recognized two algal associations. One association was characteristic of the open coast of Cape Breton Island, consisting primarily of rockweeds (*Ascophyllum* sp. and *Fucus* sp. - Fig 5b,d) with some kelp (*Laminaria* sp.) and Irish moss (*Chondrus crispus* - Fig 5a). This association was most developed in the Great Bras d'Or Channel, but was also found in St. Andrew's Channel, in West Bay and in the western portion of East Bay. The other algal association was characteristic of the warmer waters of shallow protected

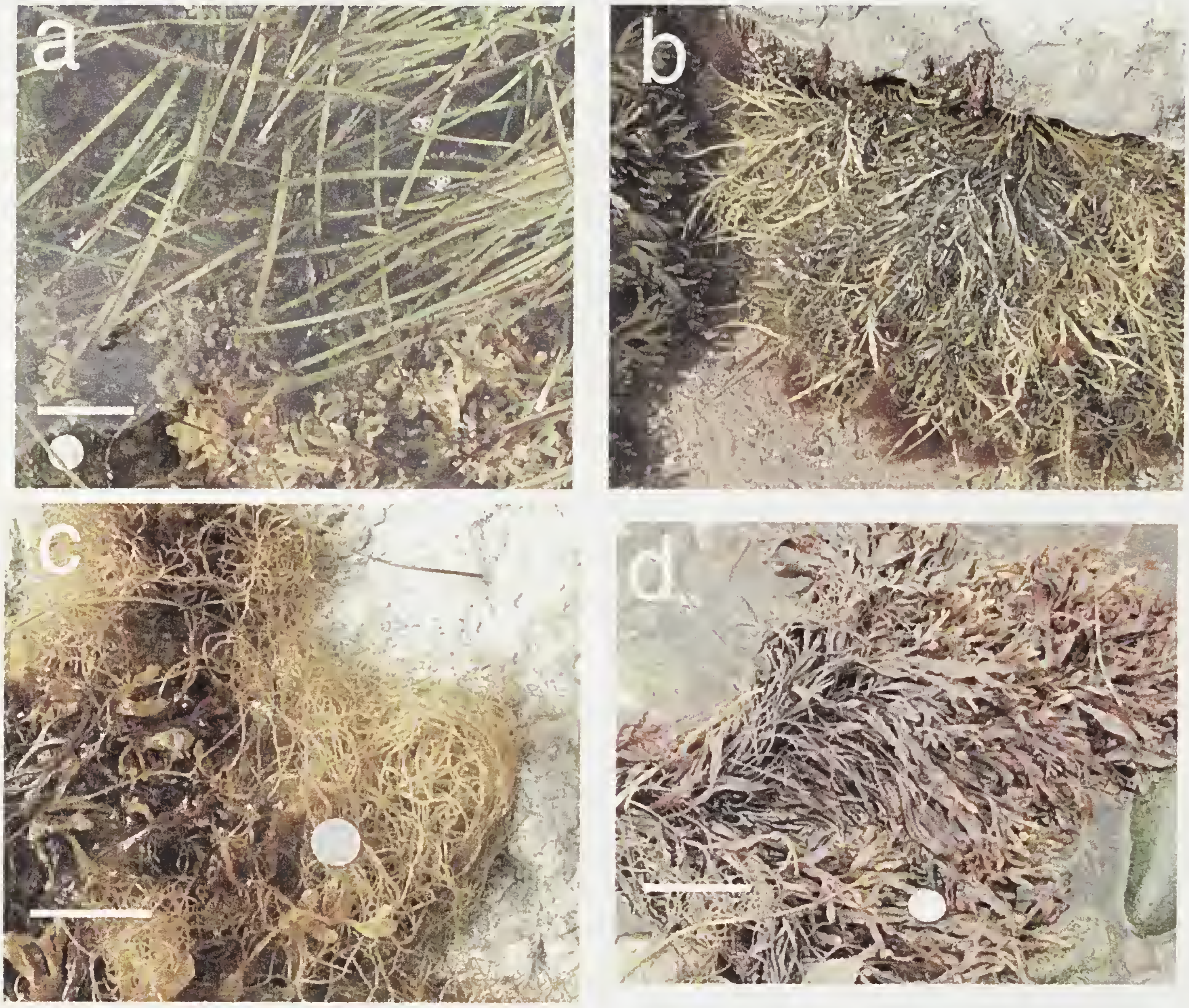

Fig 5 Photographs of eelgrass and some marine plants in Bras d'Or Lake taken in October 2001. (a) *Zostera marina* and *Chondrus crispus* near Eskasoni; (b) Rockweed *Ascophyllum nodosum* from near Barra Strait. Reddish tufts at the outer ends is a reddish epiphytic alga (*Polysiphonia lanosa*). Another rockweed, *Fucus vesiculosus* is to the left; (c) *Gracilaria tivaidae* (under coin) with some *Fucus*; (d) *Fucus vesiculosus* from Benacadie Point. White scale bar is 5 cm.

embayments, and commonly consisted of free-living forms of seaweeds such as *Gracilaria* (Fig 5c), *Ascophyllum*, and several other species. The warm-water association was found mainly in St. Patrick's Channel, Denys Basin and North Basin where eelgrass dominated. The upper reaches of East Bay and St. Peter's Inlet were also dominated by eelgrass, but the warm-water algae were poorly represented.

Biogeographic associations Because of the diversity of habitats within the Lakes, several biogeographic groups can be recognized within different taxa: Virginian, Boreal-Arctic and Arctic. The Virginian species (sometimes called warm-water or temperate) have their centres of distribution south of Cape Cod; Boreal-Arctic (cold water) species have their centres of distribution somewhere between Labrador and the Gulf of Maine, and Arctic species are found mainly in the Arctic but have isolated pockets of distribution to the south. These Arctic species are thought to be glacial relicts, left behind in localized colder areas when the ice sheets retreated northward.

The warm-water species association within the Bras d'Or Lakes is typified by the eastern oyster *Crassostrea virginica*. Oysters are near their northern limit in the Lakes and are restricted to the protected coves that warm substantially in summer. A warm-water component is also seen in the marine flora (McLachlan and Edelstein, 1971), selected nearshore invertebrates (Bousfield and Thomas, 1975), polychaetes (Fournier and Pocklington, 1984) and benthic foraminiferans (microscopic, single-celled organisms with outer shells, Vilks,1967). An Arctic component was also identified in each of the above studies, with the exception of the marine flora.

As part of a larger study of littoral marine invertebrates (mainly crustaceans and molluscs) in eastern Canada and New England, Bousfield and Laubitz (1972) had 3 collection stations in Bras d'Or Lakes. Samples were semi-quantitative with dip nets or by hand collection from shore in the St. Patrick's Channel-Denys Basin area. Based on these samples and knowledge of the seasonal temperature regime, Bousfield and Thomas (1975) grouped Bras d'Or Lakes with the southwestern Gulf of St. Lawrence. Within this region Virginian species live in close proximity with Boreal-Arctic species. A subarctic mysid (*Mysis gaspensis*; mysids are small, shrimp-like crustaceans) at the Nyanza station in the Bras d'Or Lakes was noted by Bousfield and Laubitz (1972) and they suggested that sharp seasonal and vertical thermoclines permit warm- and cold-water fauna to exist virtually side by side.

Benthic foraminiferans were sampled by an Ekman dredge or core sampler at 259 stations throughout the Bras d'Or Lakes by Vilks (1967). Depths ranged from 1-230 m. Many of the species were the same as those present further south (Mahone Bay NS, Portsmouth NH) but there was also an Arctic element. Eight groups of stations were identified based on the species composition. One group was in the outer reaches of the Great Bras d'Or Channel, while other groups were associated with particular habitats characterized by bottom type, current or depth.

Polychaetes were sampled in 1981 at 24 stations throughout the Lakes with an epibenthic sled, a Van Veen grab and a trawl (Fournier and Pocklington, 1984). Depths ranged from 9-195 m. More than 70 species were identified. These species were classified as Virginian, Boreal-Arctic, Arctic or Cosmopolitan. The Great Bras d'Or Channel was recognized as distinct based on its high percentage of Virginian species. The St. Patrick's Channel area had a similar percentage of Virginian species and perhaps would have shown a higher percentage if shallower depths had been sampled (i.e. oyster bottom). St. Andrew's Channel had the highest percentage of Boreal-Arctic and Arctic species, presumably because it is cold year-round at depth.

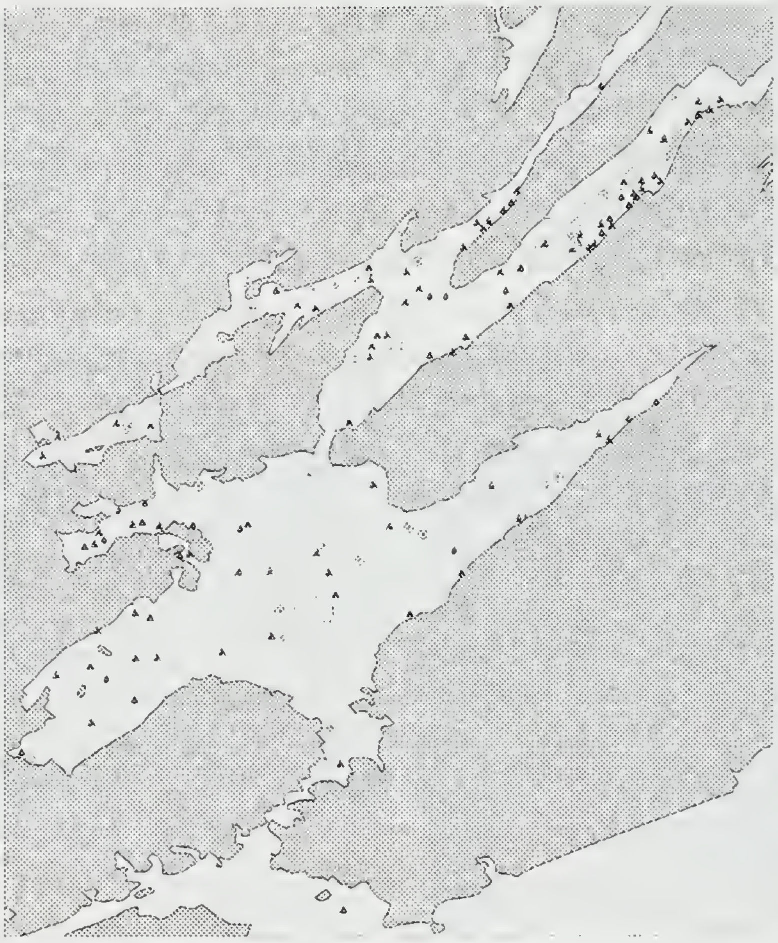

Fig 6 Locations of trawling stations in 1967 (▲, MacDonald 1968) and 1999-2000 (◈, Lambert).

Epibenthic Invertebrate Distribution: Sources of Information

Other than the above studies of polychaetes and foraminiferans, there have been no targeted studies of invertebrate distribution throughout the Bras d'Or Lakes. Trawls or drags have been used in several studies of the fish fauna and some epibenthic invertebrates were recorded along with the fish (Table I, Fig 6). Since trawls are limited to bottom depths of greater than 5-10 m, the shallow water epibenthos is under-represented in these data sets. In addition the tow lengths are several kilometres, so the distribution data from trawl surveys are coarse in scale. Resource assessment and fishery data are available for some commercial species such as lobsters and oysters.

Table I. Studies in the Bras d'Or Lakes that have documented the distribution of large epibenthic invertebrates. Stn = station. nm = nautical mile. =1.855 km

Dates	Objective	Methods	Benthic invertebrate speciesgroups recorded	Locations	Reference
May 1951-Aug. 1952	Aspects of the biology of codworm (now known as sealworm)	Drags - 3 stations sampled seasonally	Some identification to species of large and small crustacea, bivalves, starfish, anemones, others	Baddeck Bay, Kempt Head, Whycocomagh Basin	Black 1976
Sept-Oct. 1967	Fish population assessment	Trawl (3/4 Yankee 35), 115 stn, tow for 25-120 min (average 3 nm)	Lobsters, crabs scallops	Throughout	MacDonald 1968

Table I (cont'd)

May 1999, 2000	Survey of fish distribution, focus on cod	Flounder trawl 21 stn in 1999; 18 in 2000, tow length 1 nm	Lobsters, crabs, mussels, scallops starfish, urchins	Throughout	Lambert (unpublished)
Summer 1999, 200	Survey of green crab distribution	Cylindrical wire traps	Crabs	Throughout	Paul (unpublished)
Oct. 2001 distribution	Survey of lobster	Wire lobster traps	Lobsters, crabs	Cape Dauphin to North Basin; East Bay	Tremblay (unpublished)

Traditional knowledge of the Bras d'Or Lakes biota comes from both the Mi'kmaq and non-native communities that surround the Lakes and maps of distribution for some species have been completed (Eskasoni Fish and Wildlife Commission and Dept. of Fisheries and Oceans, 1996). Finally there have been several biological studies within the Lakes that are area- and or group- specific. These include recent trapping studies to document the distribution and relative abundance of green crab and lobster. Some of the results of these latter trapping studies are provided here.

The above sources have been used to compile a list of the known invertebrate fauna within the Bras d'Or Lakes[1]. While the list is probably fairly complete for the shallow water fauna, the deeper areas of the Lakes are less studied and probably contain undocumented species. The list for decapod crustaceans (species with five pairs of appendages attached to the thorax), mollusca and echinoderms is presented in Table II. Unless otherwise stated, the common names used in this paper correspond to the scientific names in Table II.

Table II List of large epibenthic animals found in the Bras d'Or Lakes. Included are Decapoda, Mollusca and Echinodermata. For source, see text footnote 1.

Taxon or Group	Taxon or Group
Phylum Arthropoda, Class Crustacea, Order Decapoda *Homarus americanus* - Lobster *Cancer irroratus* - Rock crab *Pandalus montagui* - Shrimp *Carcinus maenas* - Green crab *Crangon septemspinosus* - Sand shrimp *Spirontocaris* sp.- Shrimps Hermit Crabs	Phylum Mollusca, Class Gastropoda *Littorina* sp. - Periwinkles Limpets *Euspira heros* (formerly *Polynices heros*) (Native oyster drill or moon snail)
Phylum Echinodermata, Class Asteroidea *Asterias vulgaris* –Starfish *Solaster* sp. – Sun Stars	Phylum Mollusca, Class Bivalvia *Mytilus edulis* - Blue mussel *Mytilus trossulus* – Blue mussel (very similar in appearance to *M. edulis* but with weaker shell) *Yoldia limatula* – File yoldia

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[1] The list was generated by T. Kenchington and E. Carruthers for an unpublished document ("Unamapaqt: A description of the Bras d'Or marine environment") commissioned by the Unama'ki Environmental Committee of the Union of Nova Scotia Indians

Table II (cont'd)

Phylum Echinodermata – Class Ophiuroidea
Brittle stars

Phylum Echinodermata – Class Echinoidea
Strongylocentrotus droebachiensis
– Sea urchin

Phylum Echinodermata – Class Holothuroidea
Sea cucumbers

Phylum Mollusca, Class Bivalvia (cont'd)
Hiatella arctica – Arctic rock borer
Crassostrea virginica –
Eastern or American oyster
Mercenaria mercenaria – Quahog
Ensis directus – Atlantic razor clam
Mya arenaria – Softshell clam
Spisula solidissima – Bar clam
Placopecten magellanicus – Sea scallop
Anodonta sp. – Freshwater mussel

Life Histories of Epibenthic Invertebrates

Benthic invertebrates have a diversity of life histories. Eggs are fertilized externally (e.g. bivalves) or prior to release (e.g. crustaceans). Most epibenthic invertebrates have a planktonic larval stage, but upon settling, different species adopt a sedentary (e.g. bivalves) to mobile (e.g. lobsters) existence. Growth is continuous in most groups but is discontinuous in crustaceans which shed their outer shell during the molting process. Life spans can be one to many years. Feeding can be by filtration (e.g. bivalves), grazing (e.g. sea urchins) or by active predation (e.g. lobsters, crabs).

Benthic invertebrate females are typically highly fecund. A one pound female lobster can produce 10,000 eggs in one clutch and many more in her lifetime. Adult oysters and sea urchins can produce millions of eggs per year. The size of the larvae at hatching is related to the number produced: lobster larvae are 5-10 mm in length while oyster larvae are less than one thirtieth this size. In some groups (e.g. bivalves, sea urchins), fertilization is external, with eggs and sperm released to the water during spawning. In these groups it is critical that mates be nearby or fertilization will fail. In other groups (e.g. lobsters, crabs), fertilization is internal, or at least takes place while eggs and sperm are attached to the animal. Overall fertilization success is higher with internal fertilization, and species that use this method typically have lower fecundity than species with external fertilization.

The lobster *Homarus americanus* passes through 3 larval stages and a postlarval stage. Only the postlarva, with its well-developed antennae and claws, is readily recognizable as a young lobster. Larval stages 1-3 are strictly planktonic (floating with the currents), while the post-larva begins to spend more time near the bottom, and has good swimming ability. Crab larvae pass through several zoeal stages (marked by long anterior and dorsal spines) and a megalopa stage (relatively crab-like, this is the stage prior to metamorphosis to the adult form). Bivalve larvae are sometimes called veliger larvae, characterized by a thin shell and a velum. The velum is a two lobed organ with fine hair-like cilia that is used for locomotion and feeding. Sea urchin eggs are fertilized externally and develop into echinopluteus larvae, which are characterized by 4 pairs of elongated arms used for swimming and feeding.

The survival of the larvae of marine benthic invertebrates is very low (<<1%) but since many larvae are produced, only a small fraction needs to survive to maintain the population. Small differences in the survival rate can make large differences in the numbers of young juveniles in any given year. The range over which a given group of larvae is dispersed will depend upon the water currents and the duration of the planktonic period. Currents vary with time of year and local wind events; the duration of the planktonic period depends on temperature and possibly food.

Metamorphosis is an abrupt transformation from one life history stage to another. In the case of epibenthic invertebrates, settlement to the bottom is usually associated with metamorphosis from the larval to juvenile form. Some species, such as lobsters are highly selective in where they settle, preferring cobble bottoms. Other species, such as rock crab, discriminate less (Palma et al., 1999). As newly settled juveniles, epibenthic invertebrates are attractive food items and can be subject to high predation rates. Lobsters and crabs can adopt cryptic and evasive behavior, but this is not an option for sedentary species such as oysters. As they grow, epibenthic invertebrates generally become less susceptible to predation. Some species, such as lobsters and crabs become much more mobile and can undertake seasonal migrations.

The processes of larval delivery, settlement and post-settlement survival of invertebrate larvae are fundamental to the dynamics of marine invertebrate populations, and to the overall species composition of invertebrates in a given area. Research on how multiple ecological factors operate at each phase of the life cycle are needed to understand how marine communities are structured (Morgan, 2000).

Tolerances to Low Salinity

One of the key physical features of the Bras d'Or Lakes is the lower salinity compared to the open ocean (Fig 3). In other estuaries the species richness (number of species present) declines from the open ocean to a minimum at a critical salinity (usually 5-8). This trend reflects the inabilities of many species to tolerate salinity stress and to undergo extensive cell volume regulation. Further up the estuary, as salinity decreases, freshwater species begin to occur and species richness increases (Kennish, 1990). Studies on the tolerance of epibenthic invertebrates to low salinity (Table III)

Table III Laboratory studies or field observations of salinity tolerance of some epibenthic invertebrates found in Bras d'Or Lakes. None of the animals in these studies originated in Bras d'Or Lakes. d = day; Z4 = zoea stage 4.

Species	Stage	Tolerance indicator (s)	Salinity	Reference
Lobster	Larvae 1-3	50% mortality (2 d, 20 °C)	14-17	Charmantier *et al.*, 1988
	Post larvae	50% mortality (3 d, 20 °C)	12-13	Charmantier *et al.*, 1988
	Adults	50% mortality (2 d, 15 °C)	8.2-11	McLeese, 1956
Rock Crab	Zoea 1-4	50% mortality (4 d, 15 °C)	14-21	Charmantier and Charmantier-Daures, 1991
	Z4-Megalopa	50% mortality (4 d, 15 °C)	17-28	
	Adults	50% mortality (2 d, 15 °C)	8.5	
Green Crab	Larvae	100 % mortality (9 d, 17 °C)	15	Anger *et al.*, 1998
		Reduced survival and growth compared to 25 (>50 d, 17°C)	20	Anger *et al.*, 1998
	Adults	Survival over extended periods in nature	6	Anger *et al.*, 1998
Sea Scallop	Adults	50% mortality (3 d, 1 °C)	11.5	Bergman *et al.*, 1996
		50% mortality (10 d, 1 °C)	17	"
Blue Mussels	Adults	97 % survival (6 d, 10 °C)	5	Bailey *et al.*, 1996
Horse Mussels	Adults	At least 50% mortality (21 d, 21°C)	22	Pierce, 1970

Table III (cont'd)

Oysters	Adults	100% mortality (5 d, 25 °C)	7	Wells, 1961
	Adults	Reduced growth	< 14	Shumway, 1996
Sea urchins	Larvae	50% mortality (3 d, 10 °C)	23	Roller and Stickle, 1994
		50% mortality (10 d, 10 °C)	25	"
	Adults	50% mortality (3 d, 10 °C)	11	"
		50% mortality (10 d, 10 °C)	11	"

can be used as a guide to how sensitive these species might be to the reduced salinities within the Bras d'Or Lakes. The tolerances in Table III are not necessarily definitive for Bras d'Or Lakes' animals, since some species may have adapted to the conditions of the Lakes. This appears to be the case for cod in the Lakes which are more tolerant of reduced salinities than cod from outside the Lakes (Lambert, 2002). Here it is hypothesized that the relative salinity tolerances of different species in the Lakes are the same as have been measured elsewhere.

For species where both adults and larvae have been studied, it is clear that the larval stages are most sensitive. For example, a study of adult lobsters indicates that 50% can survive salinities as low as 8, but 50% of stage 1-3 larvae will survive only at salinities of 14-17. Mortalities are only a coarse measure of the effects of low salinity and sublethal and behavioral effects will occur long before animals die. Adult lobsters suffer physiological stress at salinities of 15 and below (Jury *et al.*, 1994). More examples are discussed below.

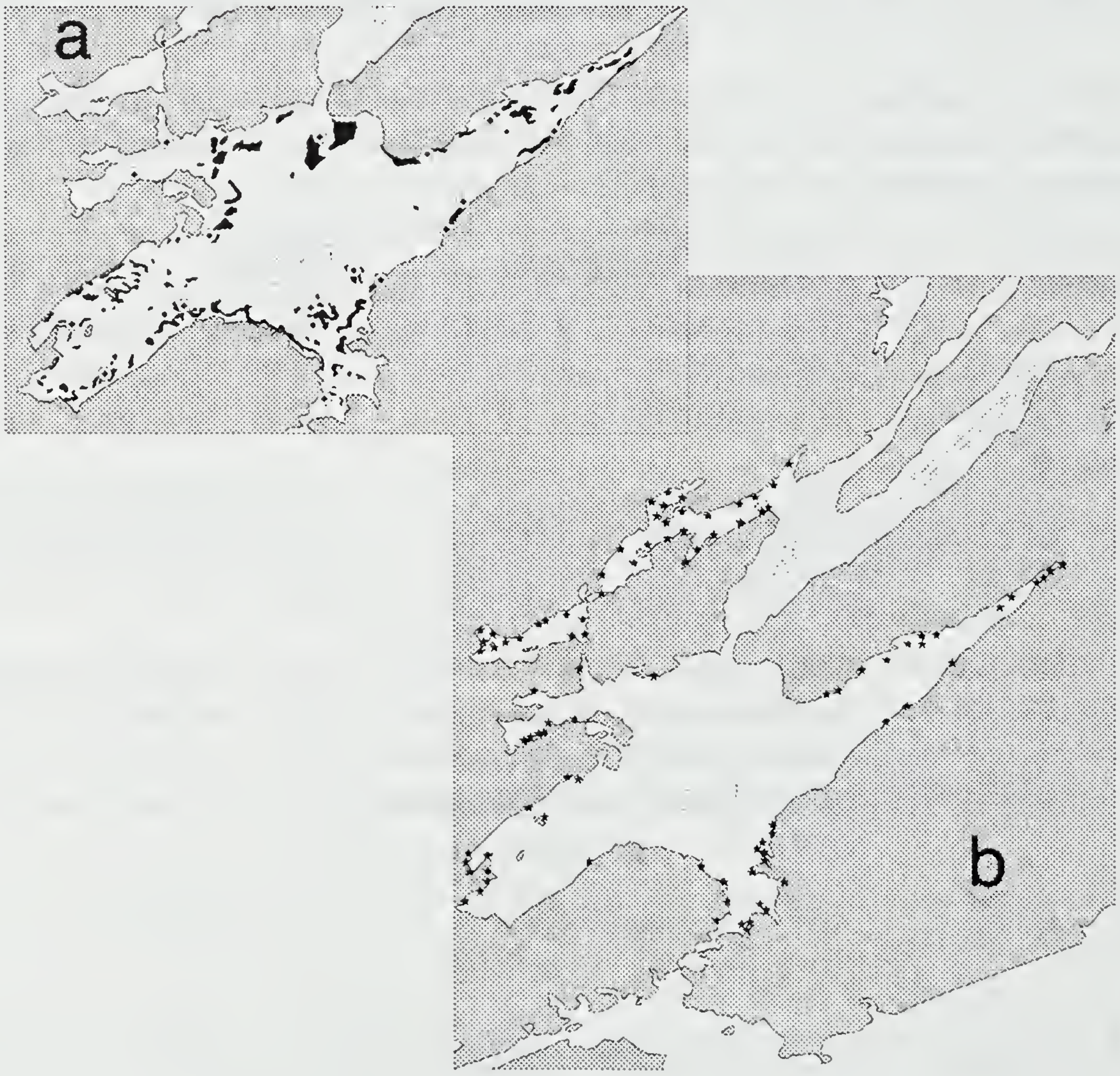

Fig 7 Maps of (a) lobsters (areas in black) and rock crabs (◈); (b) oysters (Eskasoni Fish and Wildlife Commission and Dept. Fisheries and Oceans, 1996)

Distribution, Harvest and Possible Limiting Factors of Some Key Species

The following discussion covers a number of species, but lobsters *(Homarus americanus)* and oysters are the two species with the most information. They are representative of two groups with widely different life histories (decapod crustaceans and bivalve molluscs). They serve to illustrate that the distribution and production of epibenthic invertebrates may be determined by multiple factors.

Lobsters The map based on traditional knowledge shows areas where lobsters and rock crabs are found within Bras d'Or Lake (Fig 7). Mapping traditional knowledge is ongoing and will include all of Bras d'Or Lakes when complete. Both lobsters and crabs are found primarily at depths less than 20-30 m, often in the same vicinity. The locations of lobster bottom are more or less coincident with lobster fishing effort based on a survey of the distribution of lobster trap buoys during the 1993 fishery (Stevens, 1993).

Each of the trawl surveys for fish fauna has mentioned lobsters. Black (1976) reported that lobsters were one of the characteristic invertebrates found within Baddeck Bay. The 1967 survey (MacDonald, 1968) reported a total of 47 lobsters in the 115 trawl sets. The highest catch per tow was in the Great Bras d'Or Channel (Fig 8). The overall catch rate in Bras d'Or Lake was 0.6 per tow. In the 39 trawls conducted in 1999-2000, only two lobsters were captured, one in East Bay and one in the North Basin (Fig 9). A decline in lobster abundance between 1967 and the late 1990s is consistent with anecdotal information (see below) but the surveys are not directly comparable because of differences in gear and tow length (Table I), and station distribution (Table IV).

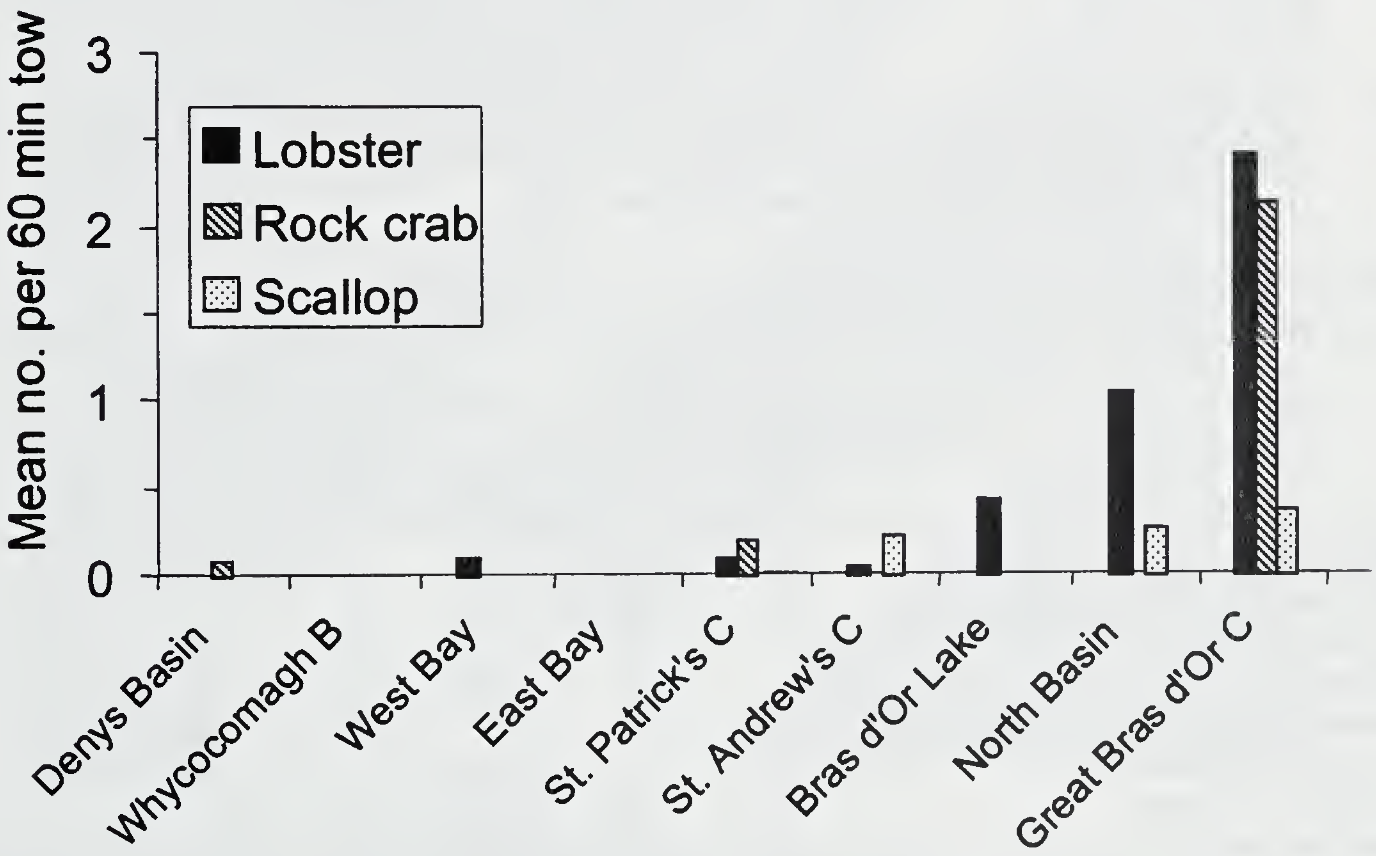

Fig 8 Mean number per standard tow of selected epibenthic invertebrates in 1967. (MacDonald 1968; Table IV) The data are standardized to a 60 min tow duration. One tow in St. Peter's inlet is not included.

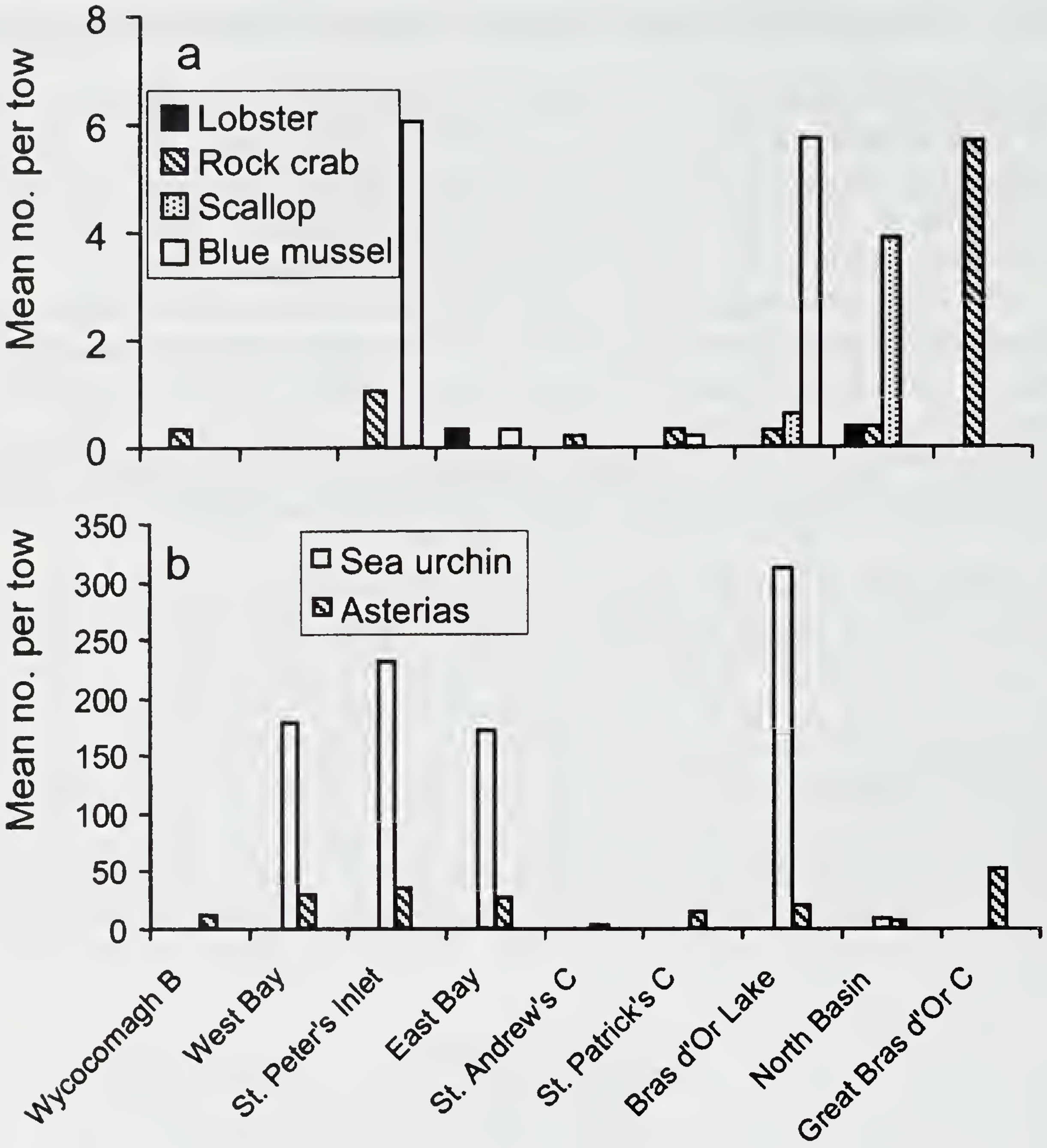

Fig 9 Mean number per standard tow of selected epibenthic invertebrates in 1999-2000 (Lambert 2001, Table IV). The data are standardized to a tow length of 1 nautical mile (= approximately 1.8 km).

Table IV Distribution of trawl survey stations in 1967 and 1999-2000.

		1967			1999-2000	
	No. Stations	Depth mean	Depth range (m)	No. stations (m)	Depth mean	Depth range (m)(m)
Denys Basin	10	9	6-15	0		
Little Narrows to Wycocomagh	4	10	6-28	4	18	7-29
West Bay	11	35	17-55	2	16	15-17
East Bay	6	51	26-65	3	20	20
Johnstown Harbour to St. Peter's Inlet	1	17	17	2	20	20
St. Andrew's Channel	34	49	22-92	5	169	27-263
St. Patrick's Channel	6	17	15-20	6	12	8-18
Bras d'Or Lake	18	33	18-107	11	66	12-134
North Basin	17	30	18-55	3	34	26-40
Great Bras d'Or Channel	8	26	18-107	3	17	10-22
TOTAL NO.	115			39		

Lobster catch rates during recent (October 2001) trapping surveys can be used to indicate relative lobster abundance (Fig 10). A total of 240 trap hauls were made from Cape Dauphin to North Basin with wire traps from a commercial lobster boat using mackerel as bait. Inside Bras d'Or Lake similar traps were employed with herring used as bait; data from 71 trap hauls are presented. Outside Bras d'Or Lake, average catch rates (number of lobsters per trap haul averaged over at least 10 traps) diminished from over 5 off Cape Dauphin and in the outer Great Bras d'Or, to less than 1 by Red Head (Fig 10). Catch rates were 1-2 on the western side of the North Basin. Within Bras d'Or Lake average catch rates were much lower, never exceeding 0.6 per trap haul. While some of this difference may be related to bait, the low catch rates within Bras d'Or Lake are consistent with the trawl data, and what is known from the commercial fishery (see below).

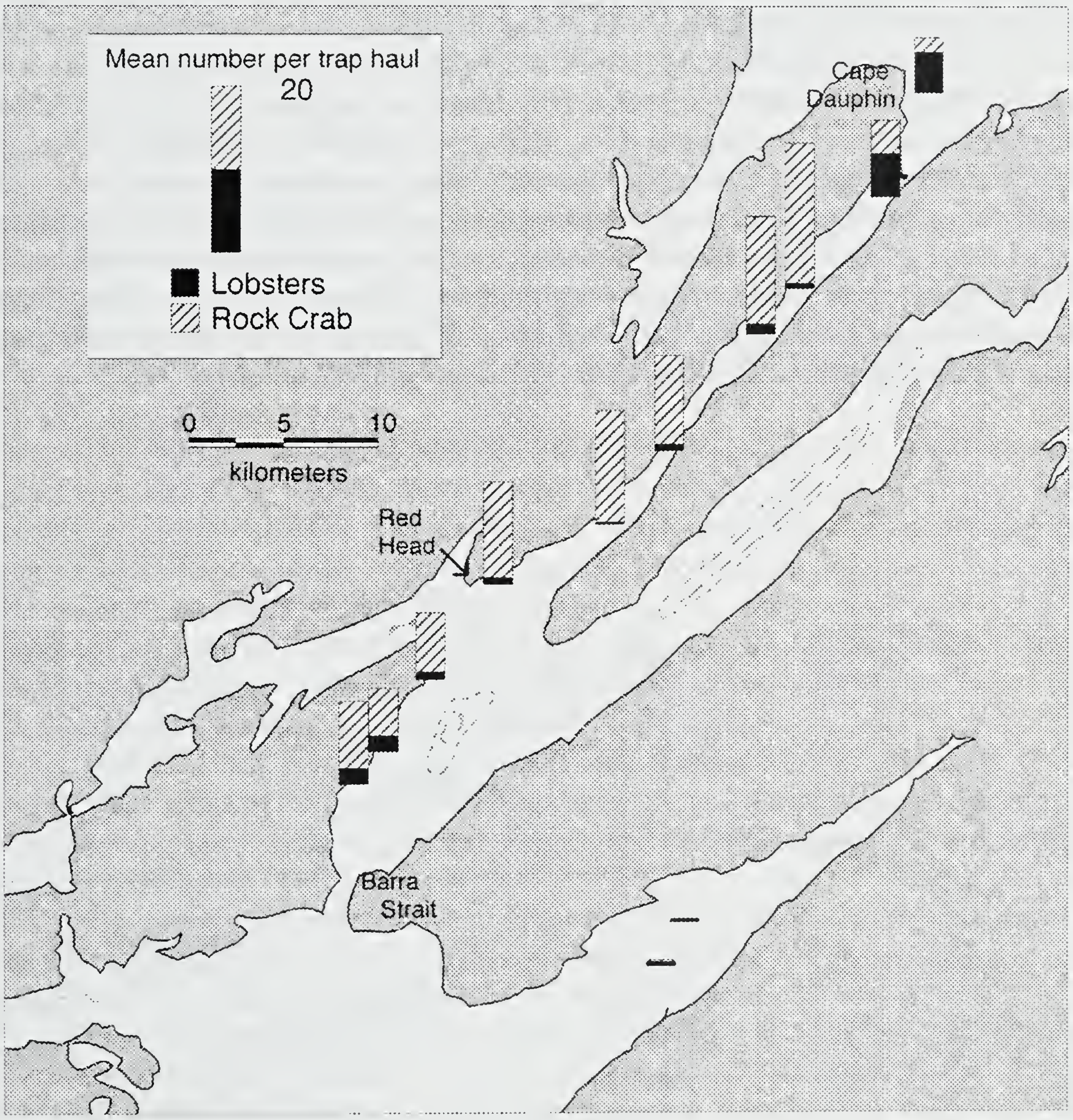

Fig 10 Mean catch per trap haul of lobsters and crabs from Cape Dauphin to Barra Strait and within Bras d'Or Lake. Data were obtained by fishing wire lobster traps from Oct. 8-12, 2001 (outside Bras d'Or Lake) and Oct. 3-5, 2001 (inside Bras d'Or Lake).

Mi'kmaq elders indicate lobsters in Bras d'Or Lake were more abundant 30 or more years ago; others who have worked in the Lakes for many years have recollections of higher lobster catches in the 1960s (Lambert, 2001). Unfortunately the apparent decline in catches cannot be reliably quantified. Prior to 1988 separate landings data for Bras d'Or Lake were not maintained by the Department of Fisheries and Oceans. Currently the lobster fishery in Bras d'Or Lake is small, with only 5 metric tons of reported landings in the year 2000. The fishery in the Great Bras d'Or Channel and North Basin is more productive, but because no fishermen set traps exclusively in this area, the fishery catch for the Great Bras d'Or Channel cannot be separated from the data for Sydney Bight.

The extent of exchange between the lobsters in the Lakes and the open coast of Cape Breton is not known. Exchange could occur at the larval or bottom-dwelling stages. A unique aspect of the lobsters in the Bras d'Or Lakes is the occurrence of a bright orange colourmorph (Fig 1a). Lobsters occur in a number of colours other than the familiar greenish-brown, including orange, blue, white, and various combinations. These colourmorphs are generally rare in lobster populations, but the orange version appears to occur in higher frequency in the Bras d'Or Lakes than outside the Lakes. Since the orange colourmorph is genetically based, it suggests the Bras d'Or Lakes lobsters may be genetically isolated to some extent. Whether such genetic isolation exists will be determined from an ongoing study of the genetics of lobsters from widely different locations in the Maritimes, including lobsters from the Bras d'Or Lakes (Jones, 2001). Whether adult lobsters move between the Lakes and the outer coast could be studied by tagging lobsters and monitoring their movement. Larval exchange would be better understood by studying the distribution of planktonic larvae in combination with the development of realistic models of the physical circulation.

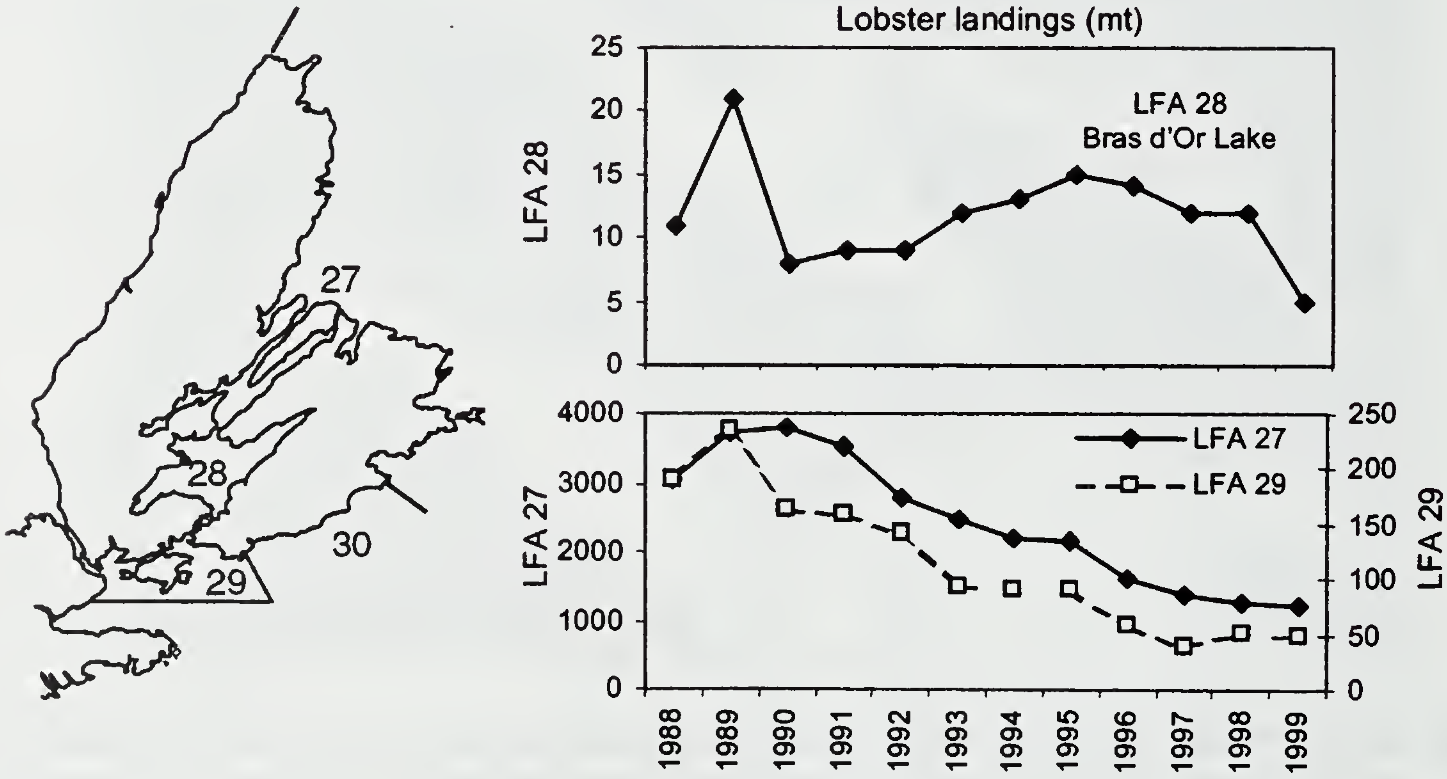

Fig 11 Map of Lobster Fishing Areas (LFAs) and lobster landings in metric tons since 1988 for LFA 28 (Bras d'Or Lake), LFA 27 and LFA 29.

Bras d'Or Lake comprises Lobster Fishing Area (LFA) 28 and reported landings since 1988 have ranged from 5-21 tons (Fig 11). Unreported catches (legal and illegal) cannot be quantified. Illegal traps have been set for many years in the Lakes (anecdotal information from native and non-native fishermen) and there is no measure of whether this fishing activity has increased or decreased over the years. Nevertheless it is doubtful that this illegal trapping approaches the scale of the licensed fishery during the 1990s. A survey of lobster buoys in Bras d'Or Lake during the 1993 spring fishery estimated a minimum of 1820 buoys (each corresponding to a lobster trap) around the perimeter of the Lake (Stevens, 1993). Most effort (68% of the buoys) was in West Bay and the mouth of St. Peter's Inlet. Fishing in the 1980s and 1990s was mainly by approximately 18 licensed commercial fishermen (license activity has fluctuated), with the First Nations fishery relatively small. By the end of 2001, all but 5 of these licenses had been purchased by Eskasoni First Nation.

Lobster landings within Bras d'Or Lake are low relative to Sydney Bight but both LFAs 27 and 28 experienced high landings in the late 1980s. Indeed the landings in LFA 27 were the highest recorded since 1874. Landings in LFA 29 (Atlantic side of St. Peter's Inlet) were also relatively high in 1989 but were far below the peak in the 1890s (Tremblay and Eagles, 1998). Similarities between Bras d'Or Lake and LFA 27 appear to have diminished since the early 1990s (Fig 11).

Scaling landings by area accentuates the differences in lobster production. Landings just north of St. Ann's Bay are coarsely estimated at 5-11 tons per km of coastline, compared with less than 0.1 tons per km of coastline in Bras d'Or Lake. Trap catch rates reflect this difference. In Bras d'Or Lake, the average catch rate of legal sized lobsters in June 2000 was 1.4 per 10 trap hauls (based on 356 trap hauls); just north of St. Ann's Bay the average catch rate during the spring 2000 fishery was 10.7 per 10 trap hauls (based on 3486 trap hauls).

Why are lobsters not more abundant in the Bras d'Or Lakes? Possible explanations are (i) marginal salinities (Fig 3); (ii) limited rocky bottom habitat (Fig 4); (iii) low food availability or (iv) insufficient egg production. The first 3 possible explanations are linked to inherent environmental limitations; the last could be the result of overfishing of lobsters in the Lakes.

Salinity in some parts of the Bras d'Or Lakes system is probably a limiting factor for certain stages of lobster. Tolerance of low salinities is lowest during the larval stages. Survival from egg to post-larva is about 25% lower at salinities of 21-22 than at salinities of 31-32, and at salinities below 20, larval survival is greatly reduced (Ennis, 1995). Reduced larval survival might then be expected in areas where salinities approach 20, such as the near surface layer of Wycocomagh and Denys Basin, Nyanza Bay and possibly East Bay.

Lobster larvae have relatively good swimming ability and are known to migrate vertically (Harding *et al.*, 1987). Although lobster larvae are most sensitive to low salinity after metamorphosis to the postlarval stage (when lobsters are about 1 cm long), in other areas (Northumberland Strait and Browns Bank) postlarvae are found predominantly near the surface (Scarratt, 1973; Harding *et al.*, 1987). Whether postlarvae in the Bras d'Or Lakes avoid the low salinities of the near surface layers would require field studies of postlarvae vertical distribution.

Sublethal effects on larvae may occur at higher salinities (e.g. 20-25) but this has not been investigated. Even adult lobsters might be stressed by the lower salinities within the Bras d'Or Lakes. In other estuaries, adults 75-92 mm in carapace (body excluding the flexible tail) show few signs of stress when salinities are dropped from 30 to 20 (Jury *et al.*, 1994), but at salinities of 10-15, oxygen consumption and heart rate both increase. This stress might be reflected in lower growth or reduced reproductive outputs. Reduced salinities might also result in adaptive seasonal movements. In coastal New Hampshire, lobsters avoid the low salinities of the upper estuary during spring but migrate up the estuary with the advance of summer (Watson *et al.*, 1999). The warmer summer temperatures may benefit lobster growth and reproduction.

Habitat in Bras d'Or Lake may also be limiting to lobsters, particularly to the juvenile stages which prefer cobble type habitat to avoid predation. In a study of the distribution of newly settled lobsters in a New England estuary, no individuals were found on featureless, sedimentary bottoms, but young lobsters were present on cobble substrates (Wahle, 1993). Within Bras d'Or Lake, Vilks (1967) reported that of 197 stations sampled with an Ekman grab, just 11 were classified as mainly boulder. Given that in Vilk's (1967) classification boulders included grain sizes down to 16 mm, it seems that areas with cobbles greater than about 10 cm are uncommon. More work is needed to quantify the type and areal distribution of cobble habitat within the Bras d'Or Lakes. New tools such as multibeam bathymetry, which has been carried out in some parts of the Lakes, should be very useful in this regard.

Insufficient food may result in lower survival or growth of lobsters in Bras d'Or Lake. For the Lakes as a whole, nutrient input is relatively low, resulting in a low level of primary production (Strain and Yates, 2002). Lobsters may be food-limited if this low primary production translates into low food for lobster larvae, or benthic food for juveniles and adults. Together with studies of food availability, studies of lobster condition inside the Lakes compared to Sydney Bight could help resolve whether food is limiting. Food availability might be a general factor limiting the production of epibenthic invertebrates in the Bras d'Or Lakes. The mean biomass per tow in the 1999-2000 trawl surveys was 13-30 times greater in Sydney Bight than in Bras d'Or Lakes (Lambert, 2001).

Another potentially important limiting factor for lobsters in the Bras d'Or Lakes is insufficient egg production. Although the proportion of ovigerous females in the Lakes is fairly high compared to the outer coast there may be just too few reproductive female lobsters to produce enough eggs to develop into a large number of young juvenile lobsters. Using catch rates as an index of abundance, there are a lot fewer reproductive females per km of coastline in the Bras d'Or Lakes than in Sydney Bight. If we accept that lobster production in the past was higher, then this indicates the habitat can support more lobsters than at present. The current low egg production may have resulted from excessive removals in the past (both legal and illegal). Given that the Bras d'Or Lakes provide less than ideal conditions for lobsters, the lobster population that does exist there may be more sensitive to fishing pressure.

Low salinity, and possibly limited habitat, food, and low egg production may interact to limit the current production of lobsters within the Bras d'Or Lakes. The relative effects of habitat availability, physiological stress and larval supply on the distribution of lobsters along estuarine gradients are complex even when good data on lobster distribution are available (Wahle, 1993). Whether the lobster population within the Bras d'Or Lakes can be enhanced requires an understanding of which factors are most important. For example if larval survival is low because of reduced salinity, then enhancement by supplementing the population with hatchery reared juveniles may be possible. If on the other hand egg production were limiting, then the best approach would be to add reproductive sized lobsters to the Lakes from adjacent areas. If habitat is limiting at the juvenile stage, then the construction of artificial reefs should increase lobster production.

Rock crab In both the 1967 and in the more recent trawl surveys the highest catch rates of rock crab *(Cancer irroratus)* were in the Great Bras d'Or Channel (Fig 8,9). The recent trapping survey for lobsters found that rock crab catch rates were highest in the middle and upper part of the Great Bras d'Or Channel, and lowest in Bras d'Or Lake. Commercial rock crab fishing occurs mainly on the ocean side of Seal Island, with catch rates comparable to Sydney Bight (5-10 kg per trap haul), but directed fishing has also occurred on an exploratory basis in the North Basin and in St. Patrick's Channel. The reduced salinities of the Lakes probably influences rock crab production more than lobsters. Adults are typically found in waters of 25-35 (Bigford, 1979) but are similar to lobsters in their tolerance of reduced salinity, with half surviving at 8.5 (Table III). The larval stages are much less tolerant. At 15°C half of zoea larvae die in 4 days at salinities of 13-17. In the megalopa stage salinity tolerance is at a minimum, with a 50% mortality at a salinity of 28 after 4 days. If the rock crab in the Bras d'Or Lakes have not adapted to lower salinities, many will be unable to achieve metamorphosis in much of the Bras d'Or Lakes.

Green crab Green crab *(Carcinus maenas)* are a recent arrival to the Bras d'Or Lakes. They were reported to be absent from Cape Breton by Pohle (1990) but were noted in Port Hawkesbury (just outside Bras d'Or Lakes) in 1992 by a lobster fisherman (Langeley, 2000). They likely entered the Lakes sometime between 1992 and 1995. Most common in protected embayments, green crab are voracious predators of bivalves such as clams and mussels (Elner, 1981). Because of the potential effect of

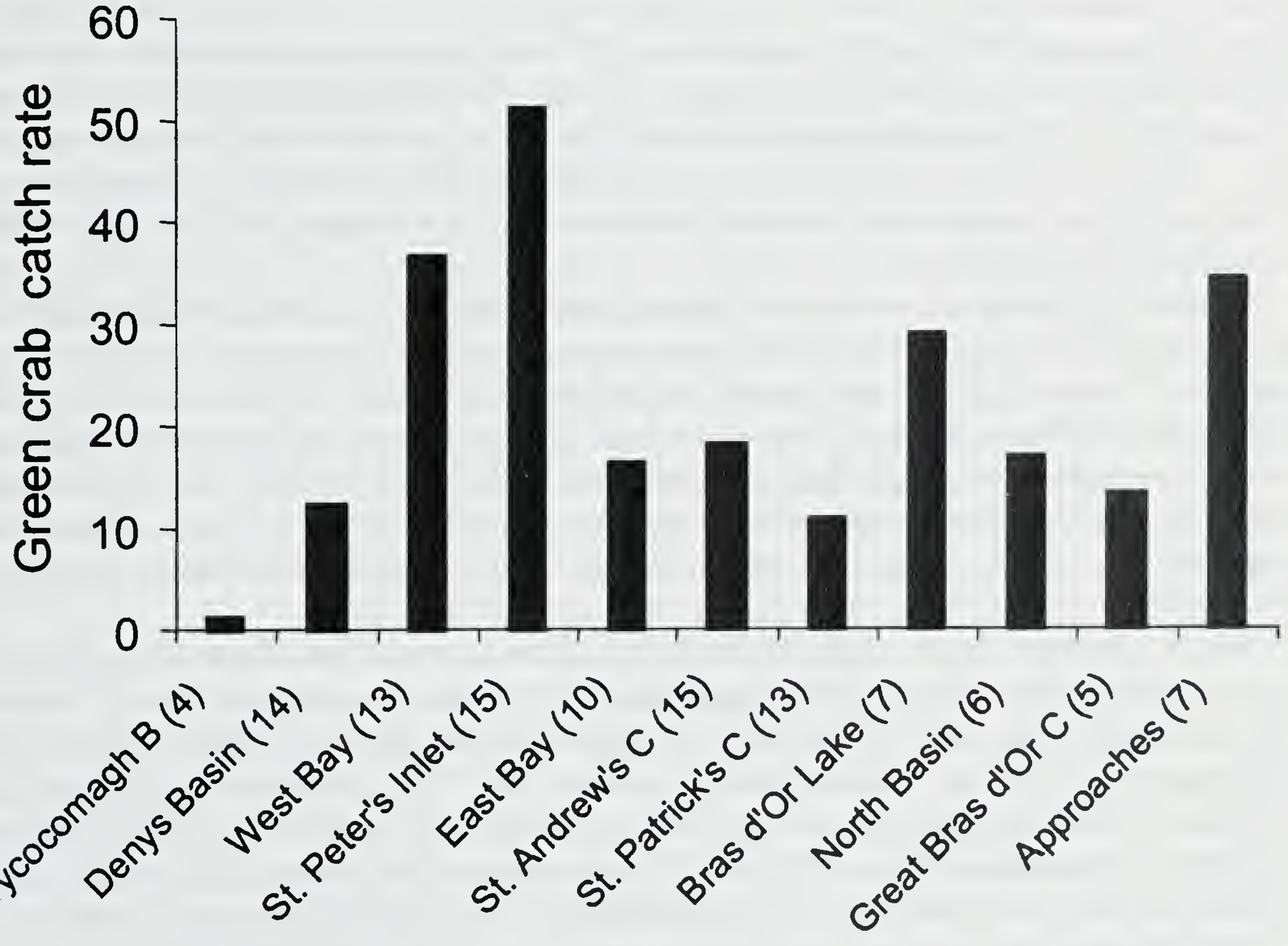

Fig 12 Green crab catch rates (no. per 3 traps set for 3-5 hr) in different areas of the Bras d'Or Lakes. The number of stations per area is in brackets. "Approaches" is between Carey Pt. and Cape Dauphin (Fig 2).

green crabs on oysters, the Unama'ki Institute of Natural Resources (UINR) initiated a study of green crab distribution and biology in 1999. Using small cylindrical wire traps (eel traps 90 cm long by 30 cm diameter) baited with fish, a total of 109 nearshore locations along the shores of the Bras d'Or Lakes were sampled from August to November 1999 and July-August 2000 (Paul, 2001). Sampling depths were usually 1-2 m, but up to 5 m. Green crabs were found throughout the Lakes, with catch rates in individual traps reaching 50 or more over just 3 h in several locations. Among the different areas of the Lakes, Whycocomagh Basin had the lowest mean catch rate (1.3 in 3 traps) while St. Peter's Inlet had the highest (51.3 in 3 traps; Fig 12).

Given the apparent sensitivity of green crab larvae to salinities less than 25 (Table III) it is expected that larval survival would be greater in areas such as the Great Bras d'Or Channel and the approaches to it, but green crab catch rates in these areas were lower than in the St. Peter's Inlet area (Fig 12). Assuming that the catch rates reflect abundance on the bottom, factors other than salinity (such as bottom habitat and wave exposure) may be necessary to explain green crab distribution in the Lakes.

The effects of green crab on the invertebrate communities of the Bras d'Or Lake are just beginning to be studied. Concern over the effects of predation on oysters is high and studies to determine the sizes of oysters green crab can consume are in progress (Paul, 2001). Green crab will also interact with other species. Cod appear to be eating substantial numbers of green crab based on cod stomach analyses (Lambert, 2001). Since rock crab also inhabit the shallow areas of Bras d'Or Lakes there is likely some competition for food. In addition green crab may prey directly on rock crab (probably those that are smaller) and vice versa. Since rock crab is an important food item for lobsters (Gendron *et al.*, 2001) any change in the abundance of rock crab caused by green crab could affect lobster populations. The options for mitigating the potential effects of green crab include changes to oyster culturing practices to minimize predation, as well as trapping and removal. The latter option is likely to be successful only in very localized areas. There is currently no commercial fishery for green crab in Nova Scotia but there are ongoing efforts to develop markets or to use green crab as bait for other fisheries.

Oysters Oysters *(Crassostrea virginica)* are probably the single most important species in the Bras d'Or Lakes from the economic and cultural perspectives. Oysters have been harvested for centuries by the Mi'kmaw, and probably since the 1800s by non-native settlers. Oysters are found in Denys Basin, St. Patrick's Channel, Whycocomagh Basin, West Bay, East Bay and St. Peter's Inlet (Fig 7b), where water temperatures increase significantly during the summer. In all locations oysters are generally found in less than a few meters depth. Trawl surveys are not effective in these areas and no oysters were recorded in 1967 or in 1999 - 2000.

The life history and physiology of the eastern oyster makes this species well suited to the Lakes. While low salinities may at times stress oysters (Medcof and Needler, 1941; Bataller et al., 1999), this does not appear to be a major problem. The timing and quantities of oyster settlement in parts of the Bras d'Or Lakes are fairly predictable (McIsaac, 2000). Oysters spawn when the temperature exceeds 20 °C for several days, usually in late June to early July. Typically the oysters settle as "spat" in 2-3 weeks (Dept. of Fish. Oceans, 1996; McIsaac, 2000). Low tidal exchange and currents, coupled with a short planktonic period, ensures high retention of oyster larvae, particularly in semi-enclosed areas such as Gillis Cove. This increases the success of oyster culturists in the collection of spat, but may also result in starvation of young oysters if their collective need for phytoplankton exceeds the local carrying capacity. The type of bottom oysters settle on will affect survival and growth characteristics (Lavoie, 1995). Spat settling on the abundant eelgrass within the Lakes may die when the eelgrass is blown ashore in storms; those settling on soft mud will sink and die. The best bottom is a mixture of silt and sand that is hard enough to support the weight of the oyster.

During the 1920s an average of 1512 barrels (each ~90.7 kg) of Bras d'Or Lakes oysters were marketed annually (Needler, 1934). As in more recent times, the quantity of oysters collected for food was not recorded. Most (90%) of the oysters in the 1920s were taken from the Denys Basin and St. Patrick's Channel areas (Needler, 1936). Currently oysters are harvested from lease and public beds. A survey of oyster distribution in 1990 indicated 85% of animals were located on leases and 15% on public beds (Dept. of Fish. Oceans, 1996). About 7% were in areas closed because of high bacterial counts. The success of oyster populations in the Lakes is affected by natural, social and economic factors. The blue mussel (*Mytilus edulis* and *M. trossulus*) is the oyster's main competitor for food and space (Medcof 1961; Fig 1d) and heavy mussel settlement can reduce oyster growth and survival. Mortality due to predators such as the starfish *Asterias vulgaris* (Drinnan, 1976) and more recently the green crab can be important. Starfish have their greatest effects when oysters are small, as above about 6 cm in length oysters are immune (Drinnan, 1976). Predation by man is at least as important—overfishing is thought to have caused the decline in the abundance of oysters on the public beds (McIsaac, 2000). Overfishing of brood stock can also threaten reproduction in enclosed areas.

Challenges for oyster culture in the Lakes include all of the above factors as well as others: reliable seed sources, reductions in oyster grow-out areas due to bacterial contamination, reliable markets (Dennis, 1998) and reductions in market value due to mud blister worms (Medcof, 1961; McGladdery *et al.*, 1993). Spat sources may be affected if blue mussels settle on oyster collectors, reducing the growth and survival of oysters, and increasing sorting costs. Blister worms (*Polydora* sp., a polychaete) can infest the inside of oyster shells in parts of the Bras d'Or Lakes. The resulting mud blisters are innocuous but can reduce the value of oysters sold in the half-shell trade.

Other bivalves: scallops, mussels, clams, and quahogs Sea scallops *Placopecten magellanicus* are typically found in tidally well-mixed areas on gravel bottoms. In both the 1967 and 1999-2000 surveys catch rates were low but they were collected mainly in the North Basin, Great Bras d'Or Channel, and St. Andrew's Channel (Figs. 8,9). Scallops are occasionally fished with drags in the outer part of the Great Bras d'Or Channel; catches are insignificant relative to commercially fished areas on the Scotian Shelf and the Gulf of Maine (Black *et al.*, 1993). Given the relatively poor tolerance of adults to low salinity (Table III), and the expectation that larvae would be even less tolerant, the reduced salinities of the Lakes must be important in limiting scallop abundance.

Blue mussels *(Mytilus edulis)* occur throughout the Lakes on harder bottom. In the 1967 trawl survey they were mentioned but not quantified. In the 1999-2000 they were most abundant in St. Peter's Inlet and Bras d'Or Lake (Fig 9). Blue mussel adults are particularly tolerant of low salinities (almost all survive at 5), indicating that low salinities in the Lakes are not an issue (Table III). The 1999-2000 trawl surveys encountered only blue mussels in the Lakes. The horse mussel (*Modiolus modiolus*) has not been recorded in the Lakes (Table II) but does occur between Carey Pt. and Cape Dauphin. The lack of horse mussels within the Lakes may be related to this species poor tolerance of reduced salinities. Study of the adults indicates 50% or more will die at 22 (Table III); larvae would presumably be less tolerant. The horse mussel is less capable of regulating cellular volume when challenged with reduced salinities (Gainey, 1994).

Soft-shell clams *Mya arenaria,* bar clams *Spisula solidissima,* razor clams *Ensis directus,* and quahogs *Mercenaria mercenaria* have all been reported in the Bras d'Or Lakes (Table II) but there are no documented studies of their distribution. The harvest of these bivalves within the Lakes has been small-scale and primarily for food; currently there is no consistent commercial fishery for these species.

Sea urchins and starfish Sea urchins *(Strongylocentrotus droebachiensus)* and starfish (mainly *Asterias vulgaris*) are currently distributed widely in the Bras d'Or Lakes. The survey of traditional knowledge reported sea urchins throughout Bras d'Or Lake, but starfish were not mapped. In the 1999-2000 trawl surveys, sea urchins dominated the invertebrate catch within Bras d'Or Lake including East and West Bays (Fig 9). Many of the sea urchins were small. Starfish were found throughout the Bras d'Or Lakes in abundances considerably greater than any crabs or bivalves (Fig 9).

The relatively high abundances of sea urchins within the Bras d'Or Lake and low abundances in the Great Bras d'Or Channel are unexpected. Laboratory studies indicate sea urchin larvae have low tolerances to low salinities (Table III). As for crustaceans, the adults are more tolerant (Table III) so once the larval stage is completed, lower salinities are less important. There are no available data on the salinity tolerance of *Asterias vulgaris.* Studies of the role of these potentially important grazers (urchins) and predators (starfish) are needed.

Sea urchins are not harvested within the Bras d'Or Lakes, but some unsuccessful exploratory fishing has occurred (Denny, 2001). Commercial operations depend on high densities of large, well-fed urchins that have a high yield of roe.

Conclusions

Key features of the Bras d'Or Lakes relevant to the distribution of epibenthic invertebrates are reduced salinities, limited physical exchange with the open coast, diversity of seasonal temperature regimes, and low tidal amplitudes. Published studies of other benthic taxa indicate that warm-water, Boreal-Arctic and Arctic faunas are found in the Lakes, probably because of the diversity of temperature regimes within the Bras d'Or Lakes.

There is still much to be learned about what limits even some well known epibenthic species within the Bras d'Or Lakes. The reduced salinities within the Lakes probably limit the distribution of several species, particularly during the more sensitive larval period. Most laboratory studies of salinity tolerance only document the lethal effects but sublethal effects on growth, behaviour and reproduction probably occur. These more subtle effects are more difficult to document. Species that are most likely adversely affected by the reduced salinities of the Bras d'Or Lakes include rock crab, sea scallops and possibly lobsters. Based on salinity tolerance, other species (green crab, sea urchins) should be more abundant in the more saline parts of the Bras d'Or Lakes but the available distribution data do not show this. Low food availability may be another limiting factor for a variety of Bras d'Or Lakes epibenthic invertebrates, but more study is needed to establish whether this is important.

The extent of lobster movement between the Bras d'Or Lakes and Sydney Bight is not known but the higher frequency of a particular colourmorph in the Lakes suggests some isolation. Lobsters in the Bras d'Or Lakes are much less abundant than on the open coast of Cape Breton Island. Possible reasons include reduced salinity, limited cobble bottom substrate, low food and low egg production. There is anecdotal evidence that lobster abundance in the Lakes is lower now than it was 30 years ago. Current low egg production may be the result of excessive fishing in the past. To better understand which factors are most important in limiting lobster abundance in the Bras d'Or Lakes, and the extent of isolation of lobsters in the Lakes, studies are needed of the distribution of all lobster life-history stages, of Bras d'Or Lakes bottom types (using tools such as multibeam bathymetry), and of the health and condition of lobsters.

The eastern oyster appears to be well suited to the areas of the Lakes with warm summer temperatures. The short larval period and semi-enclosed nature of these areas promotes high larval retention. Reduced salinities do not appear to hamper oyster production in a significant manner. The oyster populations in the Bras d'Or Lakes should thrive if innovative approaches can be developed to deal with natural predators (e.g. starfish and the newly arrived green crab), competitors (e.g. blue mussel), and overfishing. Oyster aquaculture would benefit from a reduction in the numbers of areas closed due to high bacterial counts.

The newly arrived green crab may affect a number of species within the Bras d'Or Lakes, but its overall effect on the food web is difficult to predict. Predation on bivalves such as oysters is likely significant, and studies to evaluate and mitigate this effect are needed. The interaction with other crabs, lobsters and other species is more difficult to predict since green crab may act both as a predator and as a food source.

Sea urchins and starfish are both present in considerable abundance in the Bras d'Or Lakes. Study of the potentially important roles of these species in structuring the benthic community are warranted. Clearly there is a need for more studies of the distribution and ecology of epibenthic invertebrates within the Bras d'Or Lakes. The adoption of a comparative approach with the open coast of Cape Breton Island would be profitable.

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THE GEOLOGY OF THE BRAS D'OR LAKES, NOVA SCOTIA*

J. SHAW[1], D.J.W. PIPER, and R.B. TAYLOR
Geological Survey of Canada Atlantic
Bedford Institute of Oceanography
Box 1006, Dartmouth, Nova Scotia, B2Y 4A2

The evolution of the Bras d'Or Lakes since the retreat of the last ice sheets c. 15 ka (thousands of radiocarbon years before present, where present is defined as 1950) is inferred from multibeam bathymetry, seismic reflection profiles, and sediment cores. The thickness of stratified sediment in the Lakes overlying glacial till shows that there was a step-like retreat of ice towards a late ice centre in the western part of the Bras d'Or Lakes. As ice retreated, a lake formed in the area of the modern Bras d'Or Lakes and probably drained through Little Bras d'Or Channel. Ice retreat and sea level change on the continental shelf off south-eastern Cape Breton are inferred from multibeam bathymetry that shows proglacial subaerial river channels and suggests that sea level was perhaps 50 m lower than present about 15 ka. Relative sea level appears to have risen subsequently, so that marine conditions existed in Bras d'Or Lakes basin at 10 to 9 ka. Sea level may have risen to -15 m (below modern sea level) before falling again in the early Holocene. This falling early Holocene relative sea level resulted in the creation of freshwater lakes, with a prominent erosion surface at -25 m marking the lake level in some areas. Rising sea level then resulted in a return to marine conditions in the Lakes by 4 to 5 ka.

L'évolution des lacs Bras d'Or depuis le retrait des dernières nappes glaciaires il y a 15 000 ans se révèle par la bathymétrie multifaisceaux, les profils de réflexion sismique et les carottes de sédiments. L'épaisseur des sédiments stratifiés dans le till sus-jacent des lacs démontre qu'il y a eu un retrait en escaliers des glaces vers un centre fini-glaciaire situé dans la partie occidentale des lacs Bras d'Or. Les eaux, libérées lors du retrait des glaces, s'échappèrent probablement via le canal du Little Bras d'Or pour former un lac dans le lit actuel des lacs Bras d'Or. Le retrait des glaces et les changements du niveau de la mer sur la plateforme continentale au sud-est de Cap-Breton sont mis en évidence par la bathymétrie multifaisceaux, qui montre des lits de rivière sub-aériens proglaciaires et indique que le niveau de la mer se trouvait peut-être à 50 m plus bas qu'aujourd'hui il y a environ 15 milles d'années. La hausse du niveau de la mer depuis cette époque a provoqué l'inondation des lacs Bras d'Or ancestraux il y a de 9 à 10 milles d'années, et le niveau des eaux aurait atteint -15 m avant de chuter au début de l'Holocène. Cette chute relative du début de l'Holocène a résulté en la création de lacs pour une seconde fois, avec une importante surface d'érosion à -25 m qui marque le niveau des eaux dans certaines zones. Ces lacs ont été finalement inondés par la mer il y a de 4 à 5 milles d'années.

Introduction

The Bras d'Or Lakes are a series of low-salinity lakes filling deep depressions in central Cape Breton Island (Fig 1). The lake system consists of Bras d'Or Lake in the south (Fig 2), which includes West Bay, East Bay, Denys Basin, and St. Peter's Inlet. Barra Strait provides the connection to the northern part of the Lakes, which include the Great Bras d'Or Channel, St. Andrew's Channel, St. Patrick's Channel, Little Bras d'Or Channel, and Whycocomagh Bay. The Bras d'Or Lakes are connected to the Atlantic Ocean at three locations: Great Bras d'Or Channel, with a minimum depth of about 8 m; Little Bras d'Or Channel, a 6-m-deep sinuous estuary; and the canal and boat locks at St. Peter's Inlet.

In this paper, we present and synthesize information on the geological history of the Lakes, focusing on the past ten to fifteen thousand years, during which period the last

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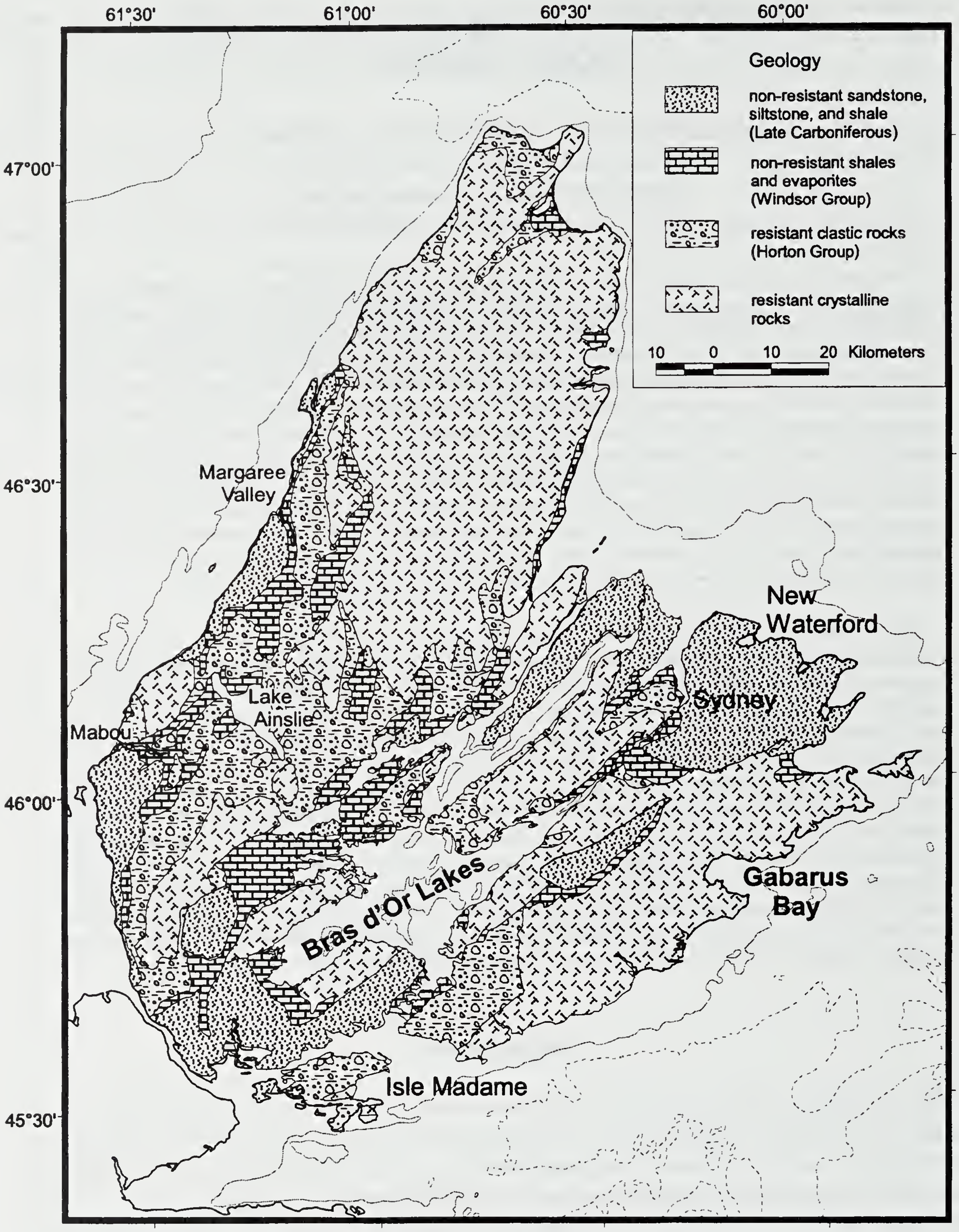
* Geological Survey of Canada contribution 2001110.

[1] Author to whom correspondence should be addressed


61°30'
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47°00'
46°30'
46°00'
45°30'
Geology
non-resistant sandstone, siltstone, and shale (Late Carboniferous)
non-resistant shales and evaporites (Windsor Group)
resistant clastic rocks (Horton Group)
resistant crystalline rocks
10 0 10 20 Kilometers
Margaree Valley
Lake Ainslie
Mabou
New Waterford
Sydney
Gabarus Bay
Bras d'Or Lakes
Isle Madame

Fig 1 Map of Cape Breton, showing location of the Bras d'Or Lakes and the bedrock geology of Cape Breton Island, Nova Scotia (simplified from Keppie, 2000).

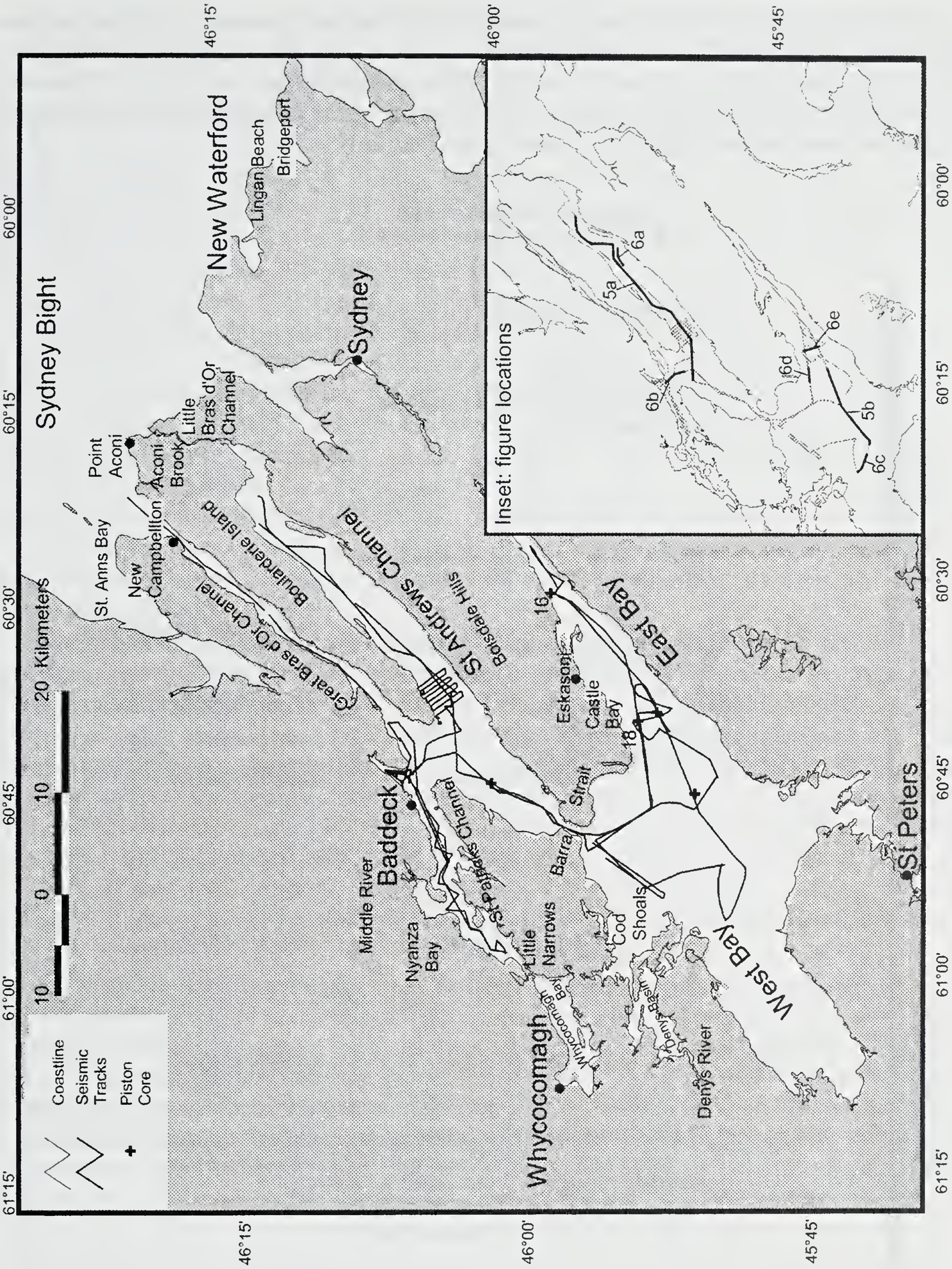

Fig 2 Map showing ship's tracks for cruise 96-155 (CCGS Hart) and tracks and core sites for cruise 85-036 (CSS Dawson). Cores 16 and 18 (discussed in the text) are numbered. The map also shows locations of seismic profiles illustrated in figures. The bathymetric contours are from Canadian Hydrographic Service field sheets summarized in Canadian Hydrographic Service (1990, 1991, 1993).

ice sheets retreated from Cape Breton Island. Our information dealing with the marine geology of the Bras d'Or Lakes comes primarily from seismic surveys and sediment cores collected from CSS Dawson in 1985 (cruise 85-036) and the CCGS J.L. Hart in 1996 (cruise 96-155), together with information from multibeam bathymetry surveys on the continental shelf off southeastern Cape Breton Island.

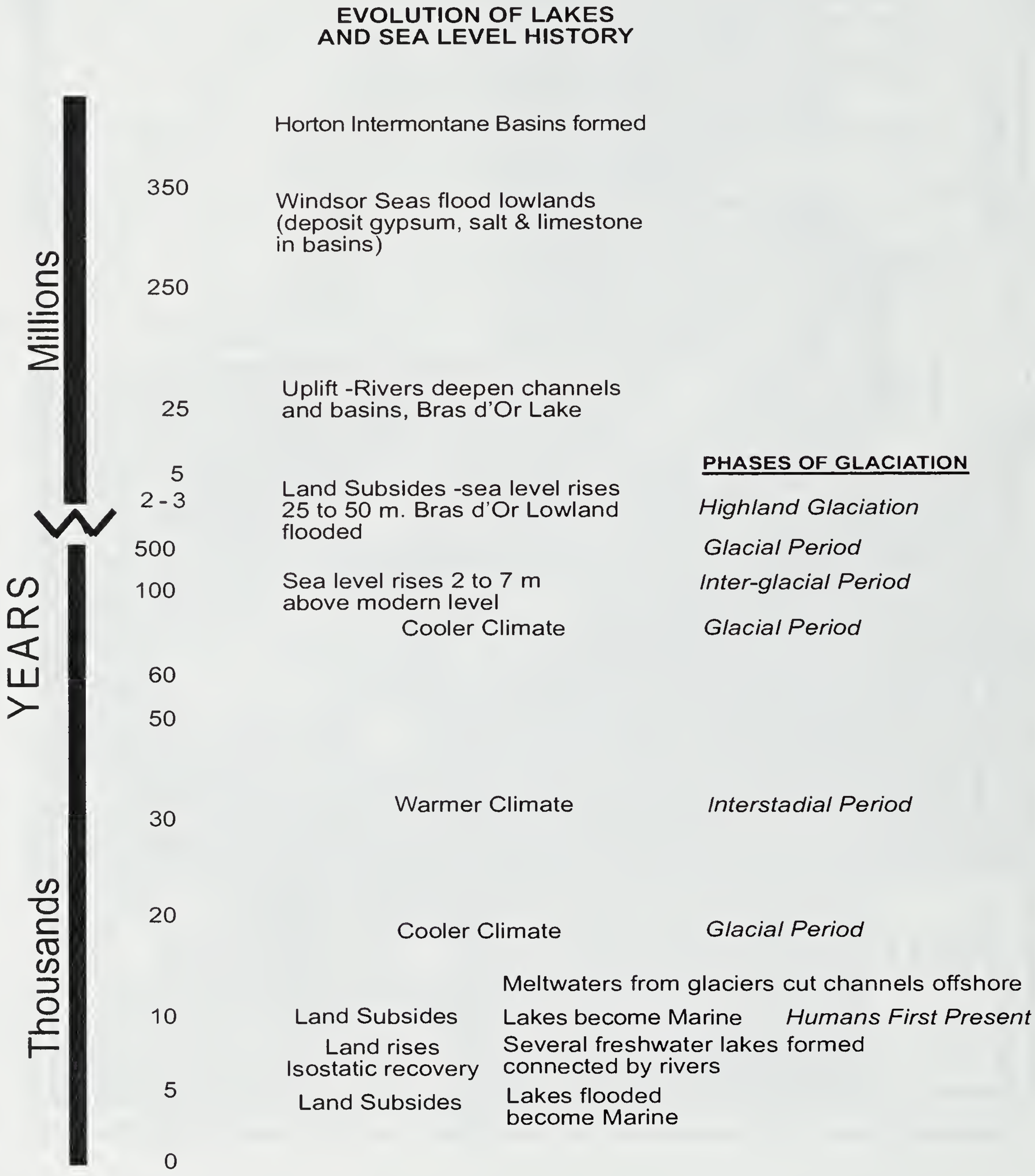
EVOLUTION OF LAKES
AND SEA LEVEL HISTORY
YEARS
Millions
Thousands
Horton Intermontane Basins formed
350
Windsor Seas flood lowlands (deposit gypsum, salt & limestone in basins)
250
Uplift -Rivers deepen channels and basins, Bras d'Or Lake
25
PHASES OF GLACIATION
5
2 - 3
Land Subsides -sea level rises 25 to 50 m. Bras d'Or Lowland flooded
Highland Glaciation
500
Glacial Period
100
Sea level rises 2 to 7 m above modern level
Inter-glacial Period
Cooler Climate
Glacial Period
60
50
30
Warmer Climate
Interstadial Period
20
Cooler Climate
Glacial Period
Meltwaters from glaciers cut channels offshore
10
Land Subsides
Lakes become Marine
Humans First Present
Land rises Isostatic recovery
Several freshwater lakes formed connected by rivers
5
Land Subsides
Lakes flooded become Marine
0

Fig 3 Geological timeline showing evolution of the bedrock geology and the phases of glaciation around the Bras d'Or Lakes. (Modified from Roland 1982 and Grant 1994).

Bedrock geology The lakes and lake basins are localised over 'weak rock lowlands' (see summary in Grant, 1994). Widespread rifting and regional tectonic plate movements in southern Cape Breton Island, at the end of the Devonian period some 360 million years ago, formed a series of small, fault-bounded basins between highlands of resistant crystalline rocks (Calder, 1998). Gravel and sand were deposited as alluvial fans at the edges of basins and in river systems and lakes on the basin floors. Lithification of these sediments produced the resistant conglomerates and sandstones of the Horton Group (Fig 1). Circa 340 million years ago the sea flooded many low areas in Atlantic Canada, including the basins of southern Cape Breton Island, depositing a thick sequence of fine grained muds and evaporites, including gypsum, anhydrite, and salt (Fig 3). The Windsor Group rocks, as they are known, underlie most of the Bras d'Or Lakes. Younger coal-bearing rocks of the Sydney Basin were subsequently deposited over much of southern Cape Breton Island.

Cape Breton Island has been slowly uplifted in the past 230 million years, largely as a result of opening of the modern Atlantic Ocean. Most of the original sedimentary rocks of Carboniferous age have been removed by gradual erosion over this period (Ryan and Zentilli, 1993), but Horton and Windsor Group rocks are still preserved in their original basins around the Bras d'Or Lakes. The Windsor Group rocks are particularly soft and thus easily eroded. This was particularly the case during the Tertiary, when rivers deepened their courses and Bras d'Or Lake and Great Bras d'Or Channel were carved out between the uplands of more resistant crystalline rocks. The resistant blocks form plateaus with elevations that increase from southeast to northwest across Cape Breton Island.

Outcrops of Windsor rocks are observed today scattered through the Bras d'Or Lakes basin, some as distinctive white shore cliffs. The dissolution of evaporites produces distinctive karst topography in the Bras d'Or Lakes basin. For example, sinkholes occur in coastal areas near Barra Strait, and are also visible in unpublished multibeam bathymetry imagery from there. The presence of these deposits may also be responsible for the extremely deep waters observed in St. Andrew's Channel. Boehner (1985) discovered through drilling on Boularderie Island that the deep areas coincide with projected outcrops of rock salt at the base of the Windsor Group. These deposits would have dissolved quickly if folding and fracturing allowed ground water to contact the salt. Full development of the deep-water depressions may have occurred in recent geologic times; the history of these features is not clear.

Regional Quaternary geology Two to three million years ago, sea level in southern Cape Breton Island was probably 25 to 50 m higher than now, which would have flooded the Bras d'Or Lakes basin (Roland, 1982); Roland also suggested that the coastal shelves stretching northward from St. Ann's Bay along the eastern coast of Cape Breton Island, and from Great Bras d'Or Channel to Nyanza Bay, are the products of these higher seas. The climate progressively deteriorated during the following Quaternary period, with highland glaciers first forming perhaps 1.6 million years ago and periods of widespread continental glaciation starting about 0.5 million years ago (Piper et al., 1994). Between glacial periods, each of which lasted many tens of thousands of years, were interglacial periods with climates similar to today. During the last interglacial period, the Sangamon Interglacial about 125,000 years BP, sea level was 2-7 m higher, forming a fossil intertidal wave cut bench along many Atlantic shores and the north shore of East Bay (Grant, 1994). The location of the interglacial paleoshoreline would not have differed much from the present shore along steeper upland areas, but would have reached several kilometres inland along lowland areas. Lake Ainslie Basin, Margaree Valley and possibly Mabou Estuary (Fig 1) were arms of the sea, which may have connected to the Bras d'Or Basin (Grant 1994). The Bras d'Or Basin would have been larger as the bordering lowlands were flooded and the adjacent uplands, such as the Boisdale Hills (Fig 2), may have been islands. Two additional marine connections at St. Peter's and through East Bay to Sydney may have existed, and the Little Bras d'Or Channel was wider (Grant, 1994).

On land, most fresh erosional features and glacial deposits were formed during the last (Wisconsinan) glaciation, from about 75 to 10 ka (1 ka = 1000 years). Eight phases of glaciation are distinguished by Grant (1994) on the basis of studies on land, although there is debate over the details and the timing, particularly of the earlier phases (e.g., Stea et al. 1998). During Phase A (62 to 47 ka) local ice spread into the lowlands from the ice cap on the highlands. There remains little depositional or erosional evidence of this event.

Phase B was a major glacial event during which foreign ice from the west spread eastward across Cape Breton Island. The direction of ice movement coincided with the orientation of valleys in the Bras d'Or Basin, facilitating the scouring of the weak underlying rocks. The ice flow is also thought to have blocked drainage as it advanced into East Bay, changing the saltwater arm into a proglacial lake called Lake Cameron about 62 ka. The timing is based on pollen studies of the nearby Castle Bay silts, deposited 20 m above modern sea level (de Vernal and Mott, 1986; de Vernal et al. 1986).

Glacial Phase C involved regional ice sheets flowing southeast over Cape Breton Island but there is little evidence of this phase in the Bras d'Or Basin. It is suggested the regional ice overrode a pre-existing ice mass, which covered the area during the early part of phase C. Indirect evidence of climatic warming and a glacial recession between ice phases C and D is provided by the occurrence of shell and wood samples which varied in age from 47 to 32 ka, and a mastodon femur sampled from a farm along Middle River which yielded ages around 32 ka (Grant, 1994).

Glacial ice in phase D flowed north across the southern lowlands from an ice centre south of Cape Breton Island. The ice was responsible for reshaping drumlin fields in the southern lowland and for depositing the distinctive bright red fossiliferous till containing marine shell fragments. During phase D there may also have been ice spreading outward from the highlands and intersecting the main northward flow of ice. Grant (1994) argued that phase D was of Mid-Wisconsinan age, but more recently Stea et al. (1998) put a strong case that the coeval northward flow in Nova Scotia was Late Wisconsinan age. The implication is that all the subsequent phases described here are younger.

Phase E was the establishment of an island centred ice cap from 15 to 13 ka (Fig 4), which is recorded by southeast trending striations and drift south of the Bras d'Or Lakes. There is also a patchy veneer of locally derived stony till from the crystalline uplands. The age of this phase given in Grant (1994) was based on Stea et al. (1992) estimates. Presumably it was the meltwater from this ice mass that cut channels several kilometres off eastern Cape Breton to modern water depths of roughly 40-50 m.

As the inland ice shrank into the Bras d'Or Lakes basin, ice in Phase F impinged on the Gulf of St. Lawrence shore, damming several valleys (including Ainslie and Margaree) with kame moraines (Grant 1994). Grant argued that phase F predated 10-11 ka.

Phase G saw the continued retreat of Bras d'Or ice into the basin as recorded by ice-marginal moraines and meltwater channels (Fig 4). This ice left moraines north of Whycocomagh and north of Nyanza Bay along the northern basin and at some stage built the large submerged ridge across St. Ann's Bay and a moraine at New Campbellton along the Great Bras d'Or Channel (Grant 1994). As the ice mass shrank and possibly re-advanced in the period 11-10 ka, a series of ice dammed lakes formed in the west, including Denys Basin. Surface organics dated at a number of sites suggested to Grant

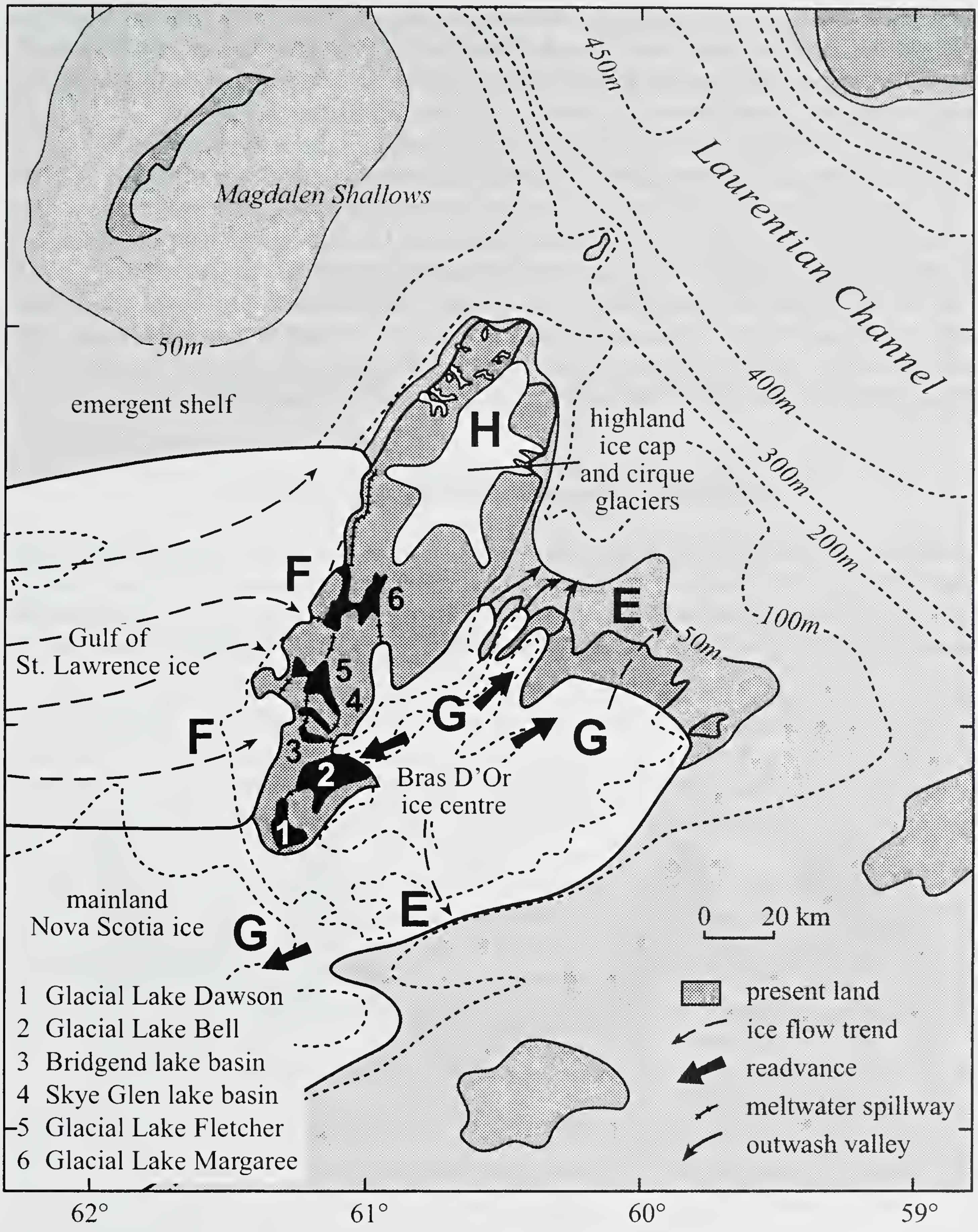

Fig 4 The final glacial events in the Bras d'Or Lakes area, adapted from Fig 114 of Grant (1994). Phase E is the establishment of an island-centred ice cap. In phase F, Gulf of St. Lawrence ice impinges on the west coast. Phase G is concentric retreatal flow and local advance of lowland ice. Phase H represents radial flow and concentric retreat of the highlands remnant ice cap. Areas between modern sea level and the -50 m isobath have an intermediate shading; these areas were emergent during stage G.

that ice had retreated to the confines of the Bras d'Or Lakes by ca. 10 ka (Mott and Stea, 1993; Miller 1997). Phase H involved a local independent ice cap on the highlands that did not impact the Bras d'Or Lakes directly but may have produced valley glaciers which extended some distance down the Middle and Baddeck Valleys.

There is a problem reconciling the scenario outlined above with the more recent work of Stea et al. (1998) and Stea and Mott (1998) who date Grant's Phase E at 12.5 – 11.0 ka. Sections where glaciolacustrine clay overlies peat conclusively show that glacial lake development from Gulf ice postdated 10.8 ka, suggesting that Phase F could be equated with the Younger Dryas period (c. 11-10 ka). In fact, for the period 11-10 ka, Gulf ice was impinging on the west coast, a small cap of ice existed in southwest Cape Breton, and a larger residual cap on the Cape Breton Highlands. It is likely therefore, that the events in Grant's phases E - G occurred in the period 12.5 – 10 ka. Phase H – the ice cap in the highlands – may have been later.

Quaternary deposits of the Bras d'Or Lakes

Seismic reflection profiles and piston cores from the Bras d'Or Lakes collected on cruise 85-036 (CSS Dawson, Fig 2) provide information on the late Quaternary history of the Lakes. The longest cores from the Lakes penetrate only the Holocene postglacial sequence (last 10^4 years), so that the character of Pleistocene glacial and late glacial

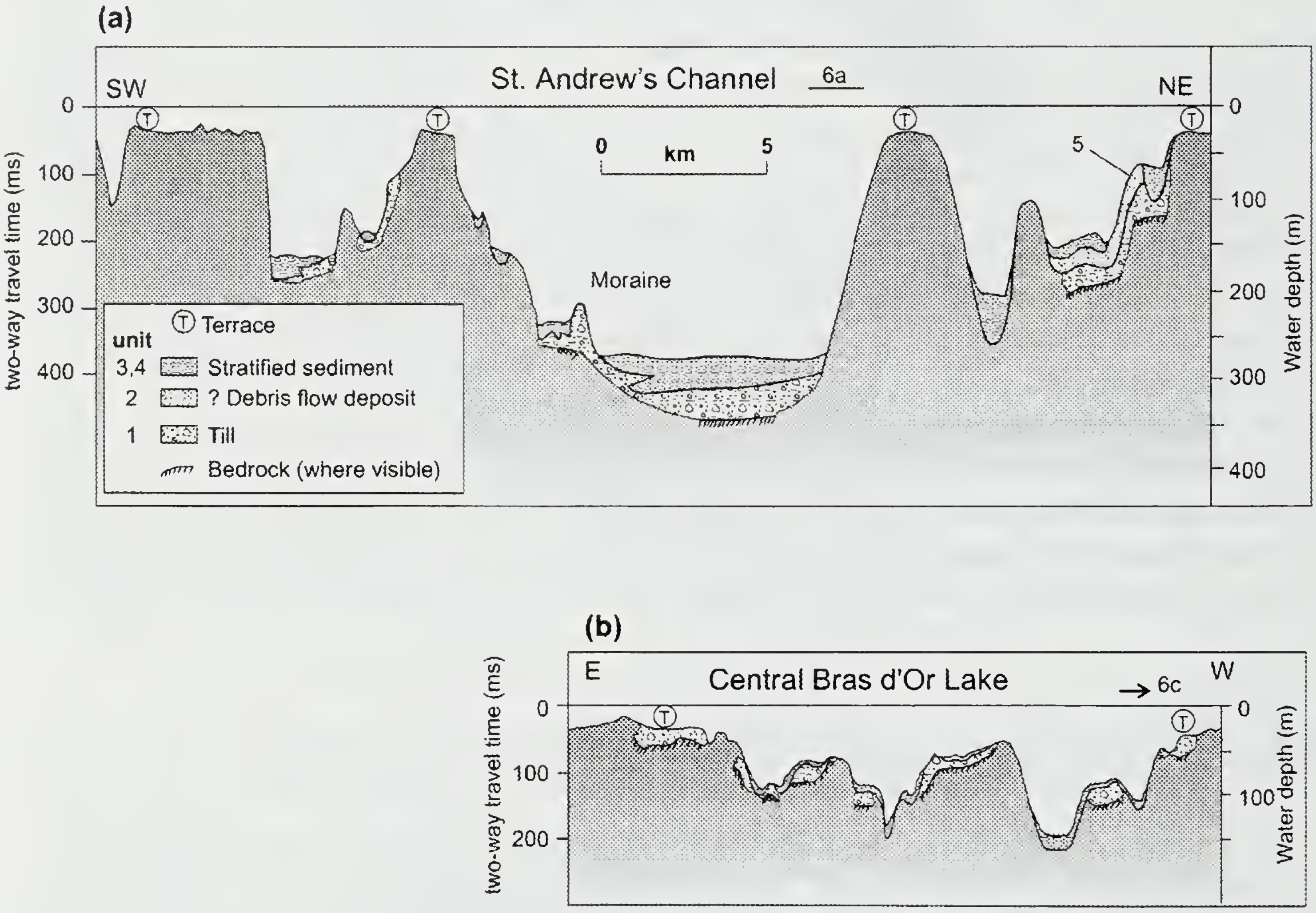

Fig 5 Line drawing of air gun profile (a) along St. Andrew's Channel and (b) at the eastern end of West Bay, showing distribution of bedrock (where visible), till and younger sediments. Refer to Fig 2 (inset) for line location.

sediments must be inferred from seismic profiles by comparison with better-known deposits on the continental shelf (King and Fader, 1986). The sequence of acoustic units recognized in the Bras d'Or Lakes (Lynch 1995) is summarized in Table I and in Fig 5.

Table I Seismostratigraphic sequence in the Bras d'Or Lakes (modified from Lynch, 1995).

Unit 4. Surficial muds, Holocene age.
  Facies 1A - stratified (near surface)
  Facies 1B - amorphous transparent (St. Andrew's Channel & St. Patrick's Channel)
  Facies 1C - weakly stratified

Unit 3. Proglacial sediments (Emerald Silt equivalent on Scotian Shelf)

Unit 2. Incoherent to weakly stratified.
  Facies 3a - thick sequence filling valleys, with positive surface relief
  Facies 3b - thin drape over till

Unit 1 Glacial till

Bedrock

Unit 1 overlies bedrock over most of the floor of the Bras d'Or Lakes (e.g., Figs. 5a, 6d), but is absent in northern Great Bras d'Or Channel. Airgun seismic profiles show that Unit 1 is typically 30 m thick in central Bras d'Or Lake (Fig 5b), with greater thicknesses where drumlins are developed (Fig 6c). Drumlins are also recognised in East Bay (Fig 6e). In St. Andrew's Channel, Unit 1 is 30-40 m thick on the deep channel floor (Fig 5a). Unit 1 is interpreted as glacial diamict (or till).

Unit 2 (Table I) consists of sediment with weak acoustic stratification that forms a drape a few metres thick over parts of the Unit 1 (Fig 6e) and resembles Facies C of Emerald Silt described by King and Fader (1986) from the Scotian Shelf. In some basins Unit 2 is tens of metres thick, with positive surface relief (Fig 6e), and has the acoustic character typical of muddy debris flow deposits. Unit 2 was deposited very close to a glacial ice margin.

Unit 3 (Table I) consists of acoustically well-stratified sediment that tends to drape over pre-existing topography (Fig 6). The acoustic character closely resembles that of the Emerald Silt (Facies A and B) of the Scotian Shelf (King and Fader 1986), which is a silty mud deposited from proglacial sediment plumes. In central Bras d'Or Lake, Unit 3 is typically about 5 m thick and generally thins towards shallower water. This suggests deposition from proglacial plumes distant from the high sedimentation rates found near the ice margin, with the upslope thinning resulting from slight winnowing by waves in shallower water. Rapid local thickening is found near Baddeck (Fig 6b), suggesting proximity to an ice margin here.

Unit 3 is either absent or < 2 m thick in north-eastern West Bay (Fig 6c), suggesting that there may have been later stagnant ice in this area. In contrast, much thicker sequences of Unit 3 are found in the north-eastern parts of East Bay, St. Andrew's Channel (Fig 6a) and Great Bras d'Or Channel, indicating a prolonged period of proglacial deposition, presumably during the late phase G of Grant (1994). Abrupt changes in thickness of this unit on either side of a bedrock ridge suggests that this ridge represents the site of a stable ice margin, so that stratified sediment to the northeast was

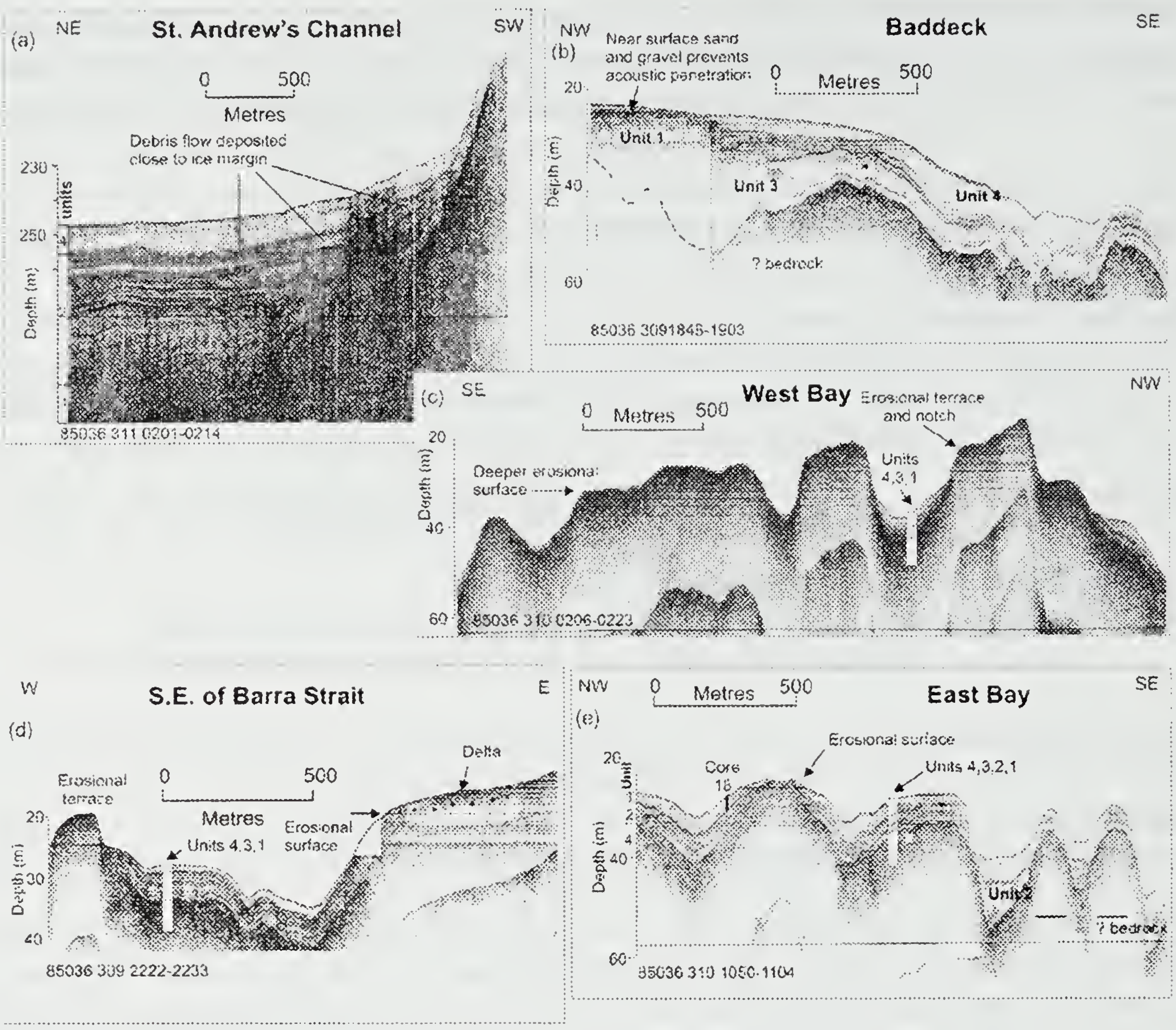

Fig 6 Huntec DTS boomer profiles showing late glacial features of the Bras d'Or Lakes: (a) proglacial sediments adjacent to southern margin of St. Andrew's Channel; (b) ice-margin sediments of Unit 3 that thicken rapidly northward towards Baddeck; (c) thin or absent Unit 2 in West Bay and the smooth erosion surfaces at -29 m and -22 m; (d) erosion surface at -19 m and delta progradation from -16 m, southeast of Barra Strait; (e) erosion surface and location of core 85036-18 in East Bay (bedrock interpreted from air gun seismic profile). Location of lines on Fig 2 (inset).

probably deposited at the same time as till to the southwest (Fig 5a). Seaward of this ridge, Unit 3 is interbedded with acoustically incoherent wedges of Unit 2, interpreted as proglacial debris flows (Fig 6a). In some areas where unit 3 is thick, acoustic penetration is masked by shallow gas.

Unit 3 is truncated by a widespread erosion surface in water depths of < 50 m, with strong planation at depths of about 20 - 25 m (Fig 6c). A small delta has prograded across this erosion surface south of Barra Strait (Fig 6d), with topsets indicating a water level as shallow as 16.5 m, apparently under conditions of falling water level. In West Bay, a smooth planar surface at a water depth of 21 m with an erosional notch (Fig 6c) contrasts with rougher seabed in shallower water.

Unit 4 (Table I) consists of mud with variable degrees of acoustic stratification. The unit partially drapes over existing topography, but is typically twice as thick in basins as over ridges. Its thickness appears strongly influenced by tidal currents between Great Bras d'Or Channel and Barra Strait. In central St. Andrew's Channel, a 10-m thick

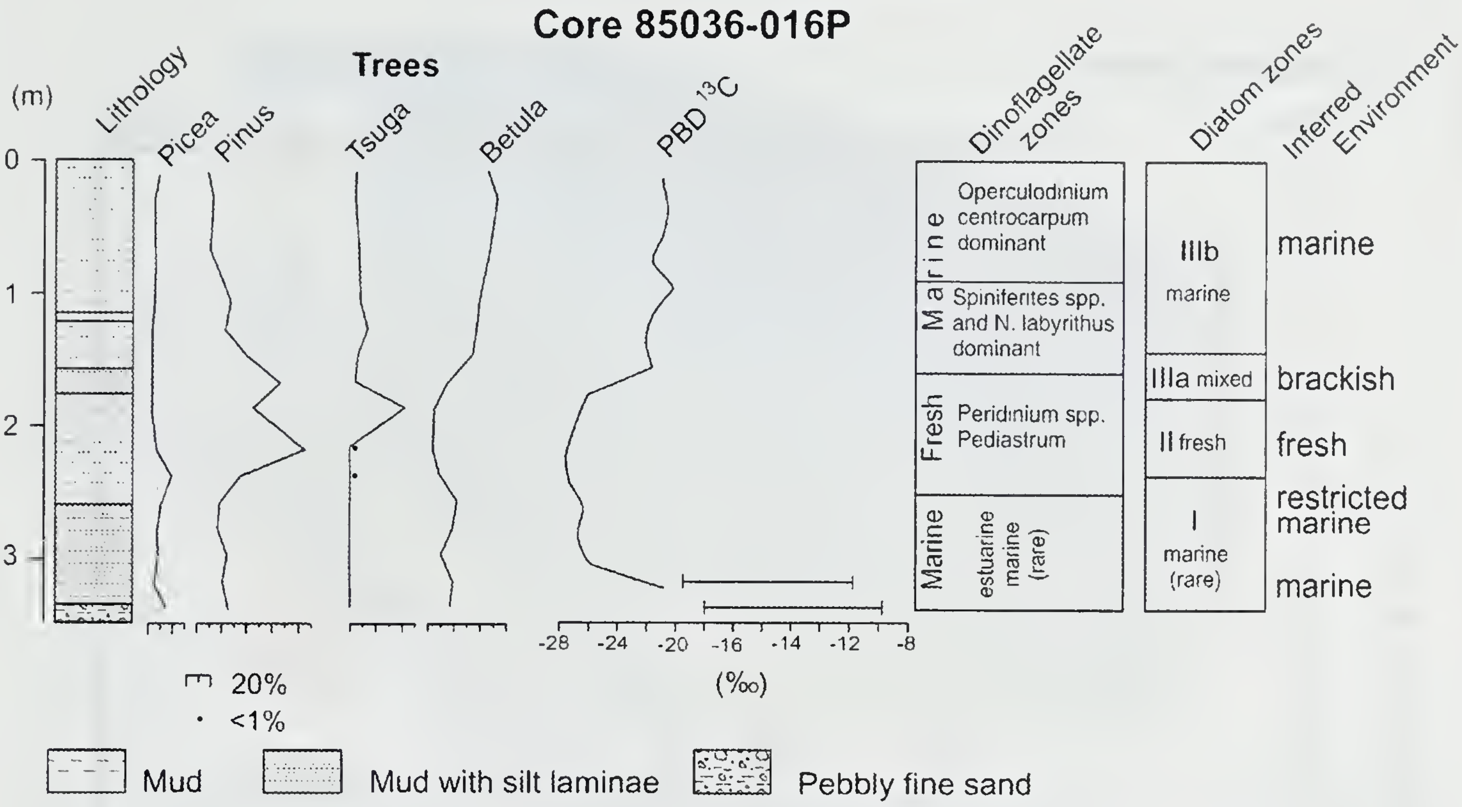

Fig 7 Summary of piston core 85-036-016P showing lithology, biostratigraphy (from de Vernal and Jetté 1987 and Lortie 1987), δ^{13} C (Hillaire-Marcel 1987) and interpreted age and environmental history. The tree pollen spectra illustrated here are spruce (*Picea*), pine (*Pinus*), hemlock (*Tsuga*) and birch (*Betula*). Dinoflagellates and diatoms are unicellular algae. The setting of core 16 is similar to that of core 18, illustrated in Fig 6e.

debris flow deposit (unit 2, recognized from its rough surface relief and acoustically incoherent character) occurs at the base of Unit 4 (Fig 6a).

Piston cores 16 and 18 from East Bay (Figs 2; 6e) both penetrate the entire thickness of Unit 4 and were stopped by a bed of sand and gravel (clasts <1 cm). Both core sites are located about 5 m deeper than a nearby erosional terrace. The basal sand and gravel are interpreted as sediment swept off the erosional terrace in the littoral zone and corresponds to a strong reflection in seismic reflection profiles (Fig 6e). Overlying sediment consists principally of mud, in some places with many silty laminae. Detailed biostratigraphic studies reveal three different depositional environments within Unit 4. The basal metre of sediment in core 16 contains sparse marine dinoflagellates (de Vernal and Jetté 1987) and very rare marine diatoms (Lortie 1987) (Fig 7). Although the sparse flora might be interpreted as reworked older material, the marine character of this interval is confirmed by isotopic analysis of organic carbon (Hillaire-Marcel, 1987). It is overlain by 1 m of sediment with mostly cold freshwater diatoms and freshwater dinoflagellate cysts. That layer is overlain by 1.5 m containing a rich variety of marine diatoms and dinoflagellate cysts, with evidence of an upward decrease in salinity and temperature. The transition between freshwater and marine diatom floras is marked by a mixed assemblage of freshwater, brackish water and marine species. No material suitable for radiocarbon dating has been found in the cores. Correlation of the tree pollen assemblages in Core 16 with the regional palynostratigraphy of Livingstone (1968) suggests that the basal marine interval dates from the *Picea* and *Betula* zone at 10 to 9 ka, the lacustrine interval from 9 ka to 4-5 ka, and the upper marine interval is younger than 4-5 ka (de Vernal and Jetté 1987).

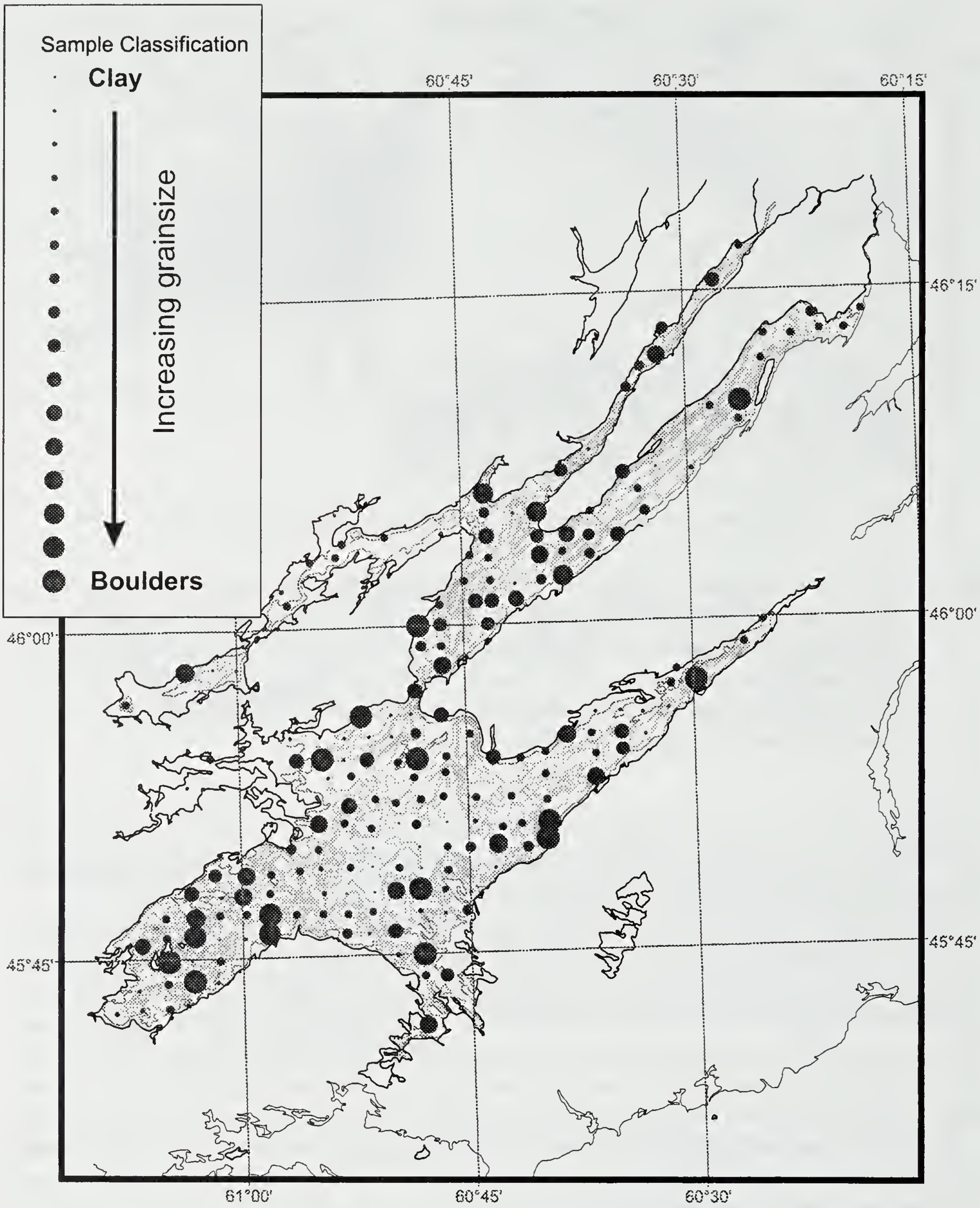

Fig 8 Map of the Bras d'Or Lakes showing generalized sediment grain size at sampling sites (modified from Vilks 1967).

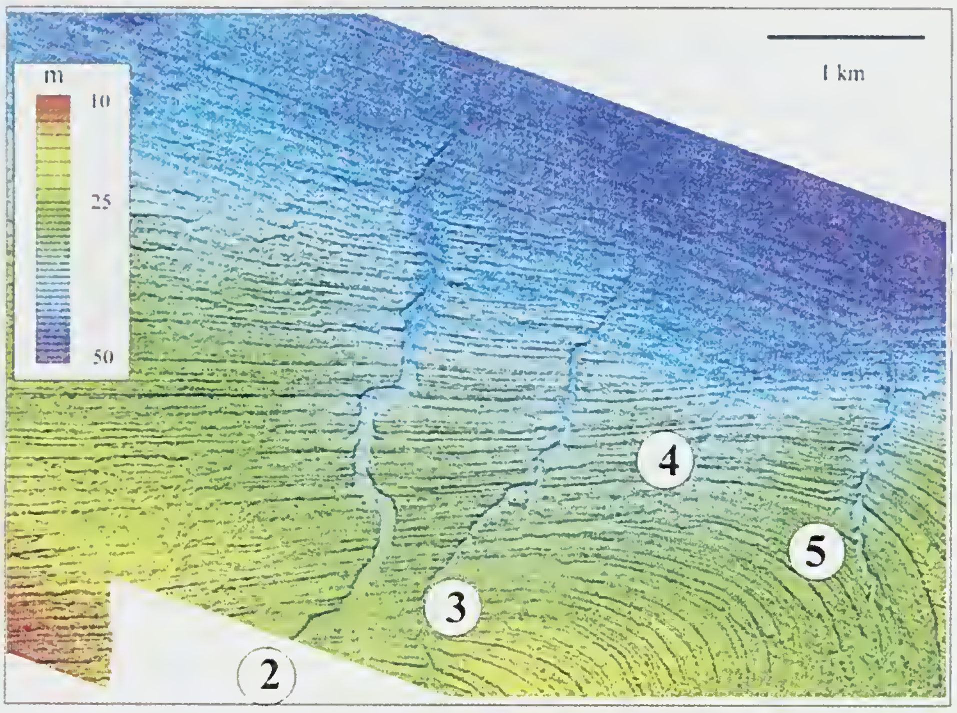

Fig 9 Coloured shaded-relief multibeam image of submerged channels (numbered) off the coast of Cape Breton in the New Waterford area. Image courtesy of R.C. Courtney (Geological Survey of Canada - Atlantic). Location of channels shown in Fig 13.

Surficial sediment distribution in the Bras d'Or Lakes (Fig 8) was described by Vilks (1967) on the basis of some 100 grab samples. This information is augmented by later bottom samples from cruise 85-036 and by sidescan sonar data reported by Cooper (1993). Deeper areas of the Lakes are floored with mud, except for sands in some areas flushed by tidal currents. More exposed shallow areas of the western part of the Lakes are commonly floored by gravelly sandy mud, resulting from erosion of till.

Postglacial changes in lake level

We have interpreted the seismic reflection profiles and cores in terms of changes in lake level and salinity. Other evidence augments these findings. Grant (1994) reported submerged channels off the northeast coast of Cape Breton, the largest of which appeared to be extensions of Aconi Brook and Little Bras d'Or Channel. They reached depths of 40-50 m, and were thought to be coeval with the later stages of the Bras d'Or Ice Cap. Wang and Piper (1982) found truncated till surfaces down to -50 m in (i.e. below present sea level) Gabarus Bay, on the south coast of Cape Breton Island; below this depth, till surfaces were unmodified. They concluded that the maximum early Holocene lowering of relative sea level was 50 m.

However, there are some apparent contradictions in published interpretations. Hillaire-Marcel (1987) and de Vernal and Jetté (1987), on the one hand, require that relative sea level was high before 9-10 ka, and that it fell early in the Holocene epoch. On the other hand, Grant (1994) believed that meltwater from late-glacial ice drained east across an emergent coastal plain that extended to the modern 50 m isobath, thus requiring that relative sea level was low in late glacial times. We examine sea-floor morphological evidence that helps to resolve this contradiction.

Submerged river valleys and erosion surfaces outside the Bras d'Or Lakes. Multibeam bathymetry surveys of the sea floor off New Waterford (Fig 1) show 5 steep-sided, flat-bottomed channels, 2-3 m deep, four of which are illustrated in Fig 9. Long-profiles

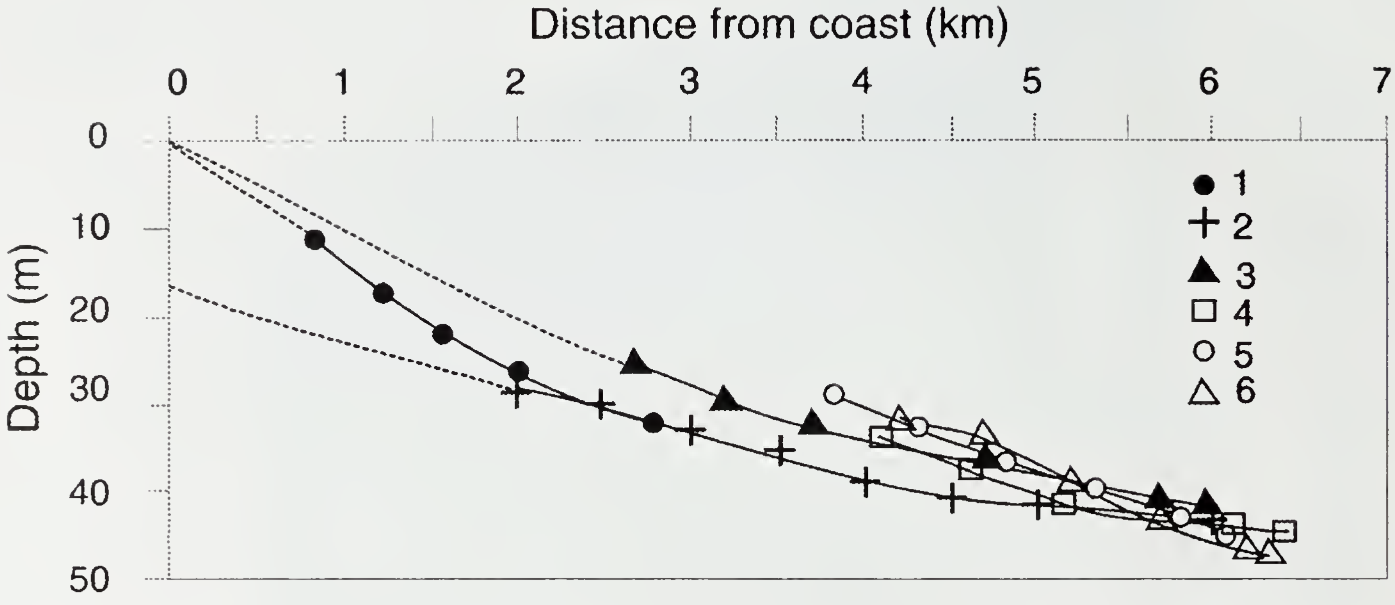

Fig 10 Long profiles of submerged channels in the New Waterford area. Location of channels 2-5 shown in Figure 9, channels 1 and 6 in Fig 13.

of the channels are shown in Fig 10. They cut across the grain of the sea floor that is formed by 2 m-high ridges of gently folded Carboniferous rock. Seismic data show that they contain 3-6 m of sediment, and do not extend farther offshore under a Quaternary cover, but end at 45-m depth. Channel 1 (Fig 13) is 70 m-wide and appears to be the extension of a small valley that runs inland 3.6 km. Channel 2 (140 m wide) lies off Lingan Beach and appears to be a continuation of a river that extends 8 km inland. Channel 3 may continue onshore as a short (<2 km) valley at Bridgeport (Fig 2). Channels 4-6 differ from channels 1-3 in that they begin far offshore, with no connection to onshore valleys (Figs 9, 10).

Grant (1994; 1997) mapped submerged channels extending offshore from the Point Aconi area. Recent multibeam bathymetry shows a channel just north of Point Aconi that extends from a depth of 16 m to a depth of ~40 m, and seismic reflection profiles show that it contains up to 20 m of sediment. The channel appears to be the offshore extension of Aconi Brook, a river than extends up the middle of Boularderie Island (Fig 2). A meandering channel just south of this is incised into bedrock, with sidewalls 3-4 m deep. It extends from 10 m to 26-m depth, and contains an unknown thickness of sediment. Its onshore extension is a short valley a few kilometres long. Neither of these is the offshore extension of Little Bras d'Or Channel.

Because some of the channels begin offshore, have linear or convex thalwegs (line connecting the deepest points along a valley), and cut across Carboniferous strata, it is possible that they were initiated as sub-glacial meltwater channels. However, sub-glacial channels elsewhere in Atlantic Canada tend to be shorter, and non-meandering. The weight of evidence suggests the channels formed sub-aerially, probably when ice had retreated to the west, and spilled meltwater across an emergent shelf, as Grant (1994) showed. However, if they drained an ice front, the channels that begin offshore imply that the ice margin was seaward of the present coast and that relative sea level was low before the start of the Holocene. The channels off Point Aconi, as noted above, contain up to 20 m of sediment. We expect that a similar buried channel probably exists offshore from Little Bras d'Or Channel which, with its steep sidewalls, bears close resemblance to submerged channels in the Point Aconi area that have been surveyed with multibeam systems.

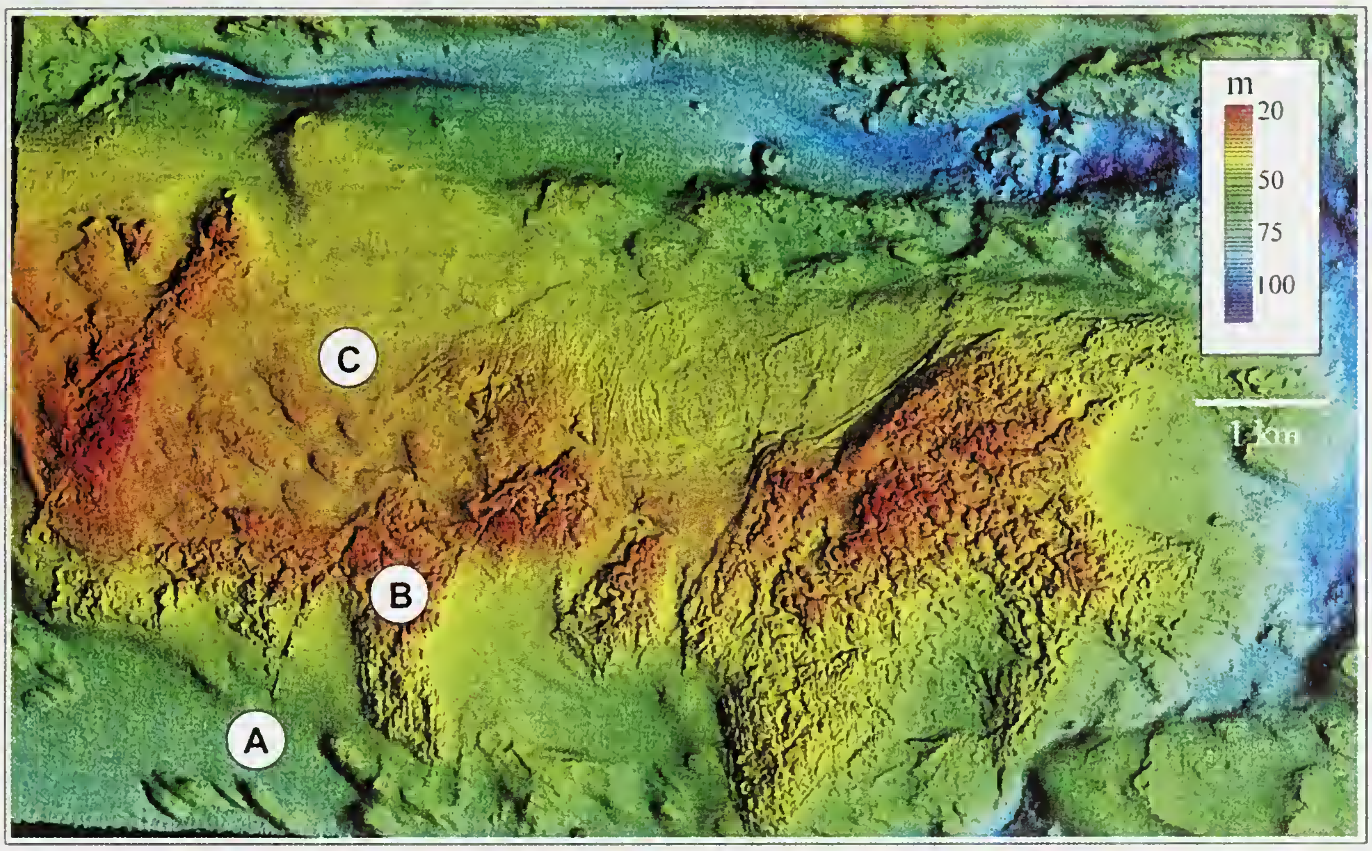

Fig 11 Coloured shaded-relief multibeam image of sea floor showing unmodified drumlins (A), rocky terrain (B) and truncated drumlins (C) in the Isle Madame area. (See Fig 13 for location). Data courtesy of Mike Li and Ned King (Geological Survey of Canada - Atlantic).

Taylor et al. (1989) reported channels incised to about 30 m below sea level, and filled with 15 m of sediment, in St. Peter's Bay, near Isle Madame, on the southwest coast of Cape Breton Island. Multibeam imagery (Fig 11) of a shoal 10 km south of Isle Madame reveals drumlins on both north and south sides with NW-SE alignments similar to those onshore (Grant, 1988). They are unmodified below depths of 55 m. Above this depth the terrain is rocky, with a cluster of truncated drumlins ('scars') at a depth of about 35 m. The postglacial lowstand was no more than 55 m deep here. Other channels outside the Bras d'Or Lakes include 8 m deep channels incised to a depth of 34 m below sea level on Pomquet Banks, in St. Georges Bay west of Cape Breton Island (Shaw et al., 1995). An unconformity is developed in early postglacial sediments at -34 m off the west coast of Cape Breton Island (Shaw et al., 1995).

Submerged river valleys and erosion surfaces within the Bras d'Or Lakes.

Unpublished results of a 1996 survey show that St. Patrick's Channel (Fig 2) contains a network of submarine channels that are commonly 100 m wide. They are incised 5-7 m into sediments with closely spaced, parallel, continuous, coherent internal reflections (having the appearance of Unit 3, Table I). The bases of the channels lie 17 m below the modern lake surface northeast of Little Narrows, and systematically deepen to a maximum of 29 m southwest of Baddeck. They are buried by 2-4 m of ponded, acoustically transparent Holocene mud of Unit 4, have no surface expression, and would therefore not appear on a multibeam image.

Unpublished multibeam bathymetry imagery from Denys Basin, in the western part of the main lake south of Barra Strait, shows a meandering river channel that extends eastward towards the middle of Bras d'Or Lake to a depth of at least 12 m (Paul, 2001); the hydrographic chart shows that this channel reaches a depth of at least 16 m. Unlike those in the Baddeck area, the channels are not completely buried by the mud.

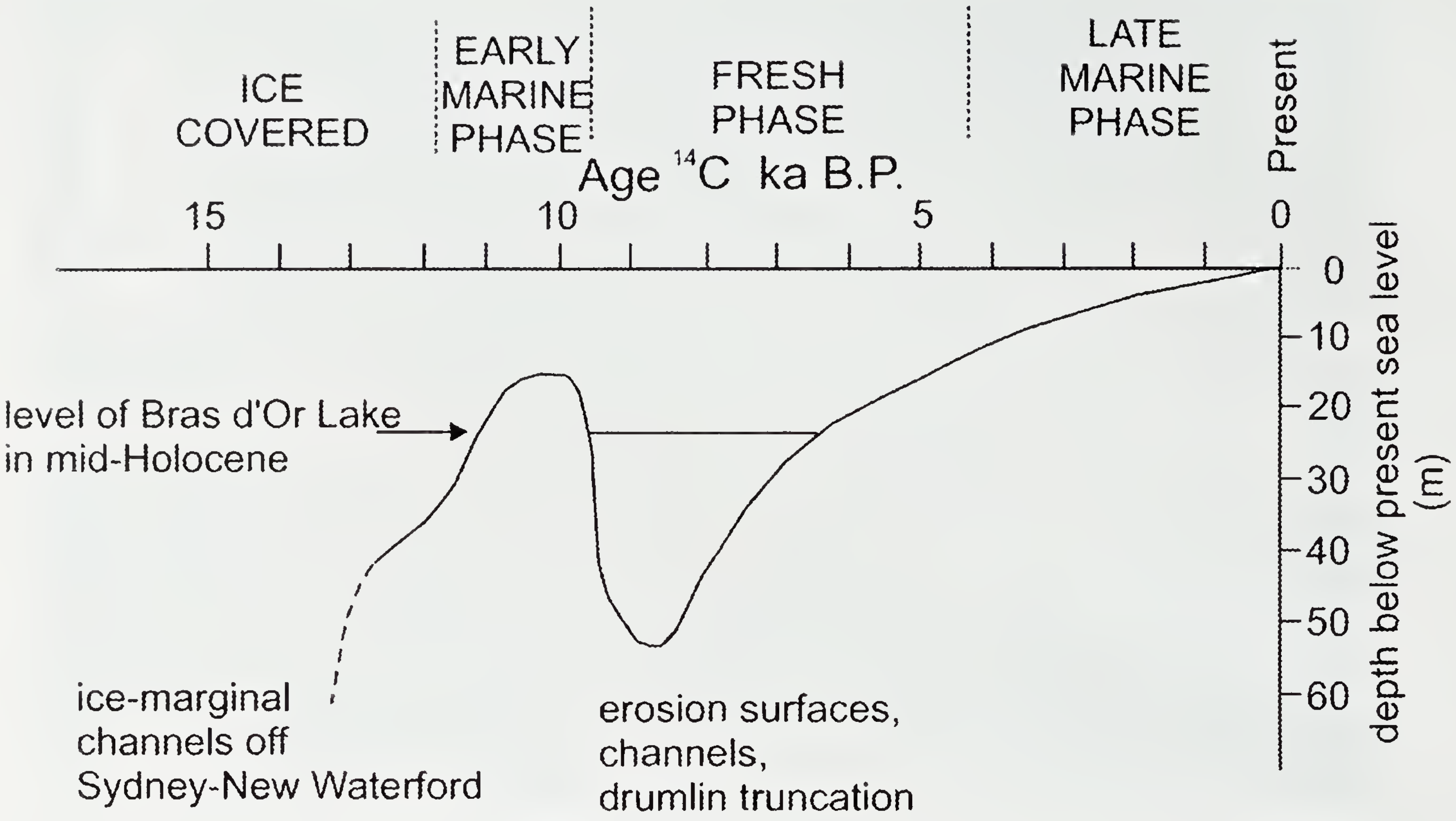

Fig 12 Model of changing sea and lake levels in the Bras d'Or Lakes region over the past 15 000 years.

The seismic data illustrated in Fig 6 show the presence of unconformities cut at the top of Unit 2 (Table I) and in marginal deltaic sediments. They are commonly at depths of 25 to 22 m, and testify to a sustained lake level at that depth. The data from the 1996 survey show that the seabed surrounding the basin just north of Cod Shoals (Fig 2) is flat, and constitutes an erosional unconformity. Acoustic reflections of Unit 3 are truncated at the sea floor to a maximum depth of 26 m. Furthermore, several channels are incised into Unit 3 to depths of 26 m. A major break of slope where the truncation zone is juxtaposed against Cod Shoals is at -24 m. Locally, shallower erosional features are seen at 18 to 20 m depth (Fig 6d).

Geography of the Bras d'Or Lakes in the last 15,000 years

On the inner Scotian Shelf, there is widespread evidence for high relative sea level as glacial retreat occurred between 18 and 12 ka. This was followed by a pronounced lowering of sea level some time in the 12 ka to 9 ka interval, and then gradually rising sea level until the present day. This resulted, for example, in the characteristic irregular 'J' shape of the sea-level curve for the inner shelf near Halifax (Stea et al., 1994). The data from the Bras d'Or Lakes suggest that a slightly different model is applicable to the evolution of the Bras d'Or Lakes (Fig 12), one with an early phase of low relative sea level.

In late glacial times, when south-eastern Cape Breton Island was covered with ice, valleys such as those in Fig 9 suggest that sea level was initially close to -50 m. As ice retreated, perhaps to the ice margin identified in the middle of St. Andrew's Channel (Fig 5a), meltwater continued to drain out through channels across the shelf, potentially deeply incising outlets such as Little Bras d'Or Channel. As ice retreated farther towards West Bay, and sea level rose, marine water eventually flooded into the Bras d'Or Lakes.

Marine waters entered the Bras d'Or Lakes, probably through the channel at Little Bras d'Or, flooding first the main lake system and eventually the head of East Bay. The pollen stratigraphy at the head of East Bay suggests an age of about 10-9 ka for this incursion. The deltaic deposits in Fig 6d may represent the limit of marine incursion at this time at about -16 m, a depth sufficient to bring sea water across the -18 m sill that separates East Bay from the remainder of the paleo-lake system. This was followed by a fall in relative sea level that eventually cut off the Lakes from the sea once again.

In the early Holocene, following the fall of relative sea level that terminated the early marine phase, the stratigraphic evidence suggests a sustained lake level at about -25 m (Fig 13). This obviously requires that relative sea level outside the Lakes was deeper than -25 m, and also that the sill was deeper than today (-8 m). A large part of the

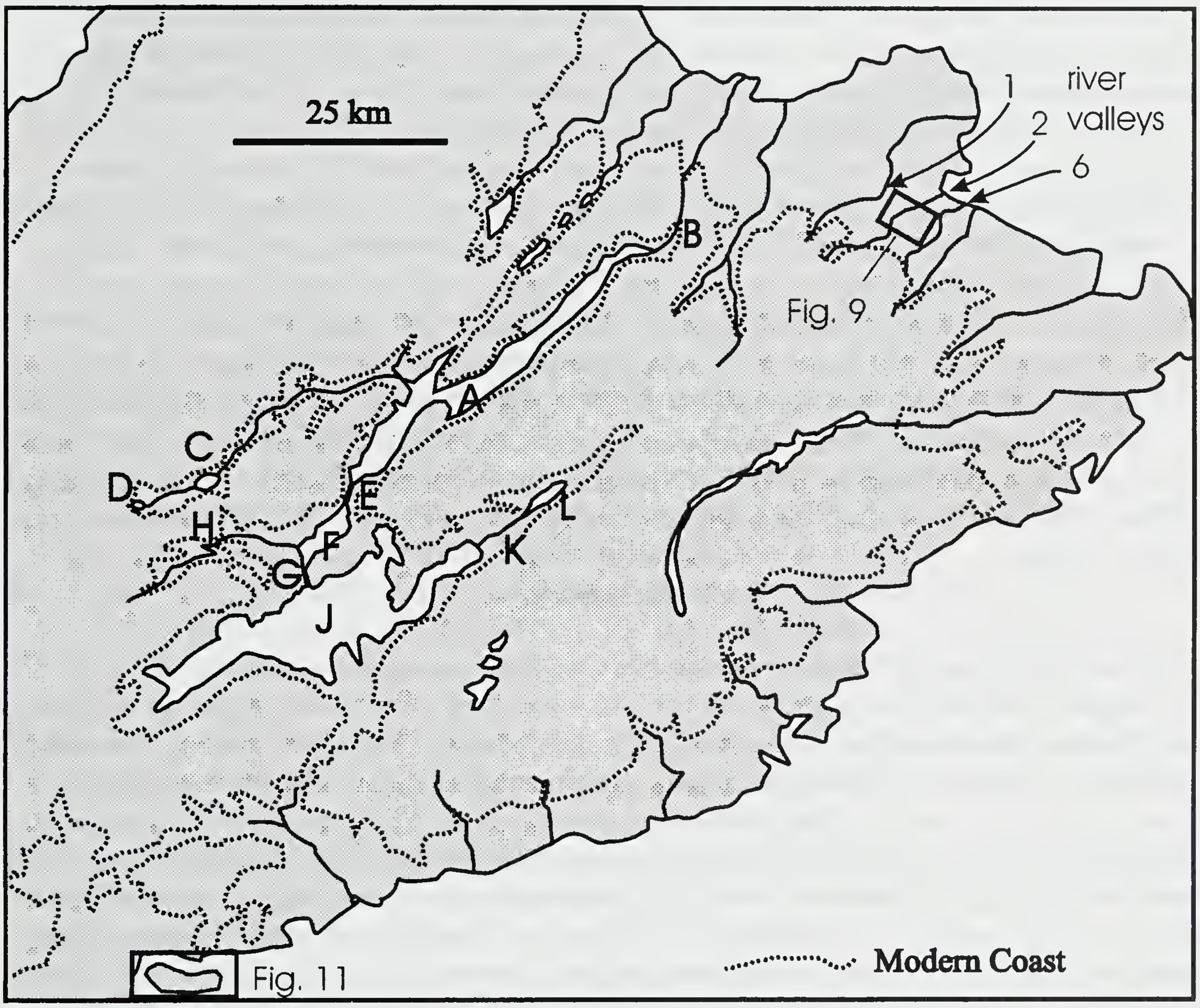

Fig 13 Suggested geography of the Bras d'Or Lakes at a -25 m water level. (A) a major part of the ancient lakes was north of Barra Strait; (B) Little Bras d'Or Channel, formerly an outlet for the lakes; (C) a small lake was located just west of Little Narrows; (D) location of a former lake in the Whycocomagh area; (E) a narrow part of the ancient lakes at Barra Strait; (F) a wider part of the lakes south of modern Barra Strait; (G) a narrow strait located on the modern Cod Shoals; (H) the ancestral Denys River that drained into the ancient lakes; (J) the largest part of the ancient lake system; (K) a sill separating the main lakes from a small lake (L) in modern East Bay. The boxes show areas of multibeam bathymetry coverage. 1, 2 and 6 are channels in the New Waterford area discussed in text and shown in Fig 9 and 10.

ancient lake (Fig 13, A) was north of the modern Barra Strait, and drained out to the ocean via Little Bras d'Or Channel (B). St. Patrick's Channel was occupied by a river that reached the lake southeast of Baddeck and drained two lakes in Whycocomagh Bay: a larger lake at -12 m immediately west of Little Narrows (C), and small lake just south of Whycogomagh at -10 m (D). The large lake was extremely narrow at Barra Strait (E), widened to the south (F), and narrowed again on Cod Shoals (G). The ancestral Denys River (H) flowed east into the lake in this area. South of the narrows at Cod Shoal, the ancient lake (J) extended to both the northeast and southwest. The lake was very constricted in parts of East Bay, and probably ended south of Eskasoni (K) where a sill may have separated it from a smaller lake at the head of East Bay (L) at an elevation about -18 m (This lake was the site of core 16; Figs 2, 7). This mid-Holocene lake was eventually flooded by the sea as relative sea level rose again. The principal modern connection to the ocean is the -8 m sill at Great Bras d'Or Channel, located on a morainal bank (Grant 1994). When this connection flooded, it is possible that the sinuous, hydraulically inefficient channel at Little Bras d'Or gradually shoaled at its landward end, perhaps due to flood-delta deposits. Depths for Little Bras d'Or Channel on CHS Chart 4367 are less than 5.5 m, although there are indications of a channel >11 m deep, perhaps the remains of a formerly deeper channel. The Little Bras d'Or outlet was probably the outlet for the mid-Holocene lakes and may have been the pathway for the incursion of marine water at about 5 to 4 ka as sea level rose again.

Miller and Livingstone (1993) showed that relative sea level in Great Bras d'Or Channel rose during the last 4000 years, reaching 1.5 m below the modern level at 0.95 ka; the rate of sea level rise was less that that registered by tide gauges in the region (see rates in Shaw et al., 1993). It appears likely that cyclic fluctuations of eustatic sea level were superimposed on long-term crustal subsidence in Atlantic Canada during the last 3000 years, and that the modern rapid increase began c. 1600 AD (Shaw and Ceman, 1999).

Conclusions

The sediments on the floor of the Bras d'Or Lakes preserve an important record of the complex sequence of events that took place during the retreat of glacial ice from Cape Breton Island and during changing lake levels in the Holocene epoch. The thickness of sediment above glacial till shows that there was a step-like retreat of ice towards a late ice centre in the western part of the Bras d'Or Lakes. As ice retreated, a freshwater lake developed behind a sill (probably in Little Bras d'Or Channel). Marine incursion flooded this lake at 10 to 9 ka and the water level may have risen to -16 m before falling again. This falling early Holocene relative sea level resulted in the creation once again of freshwater lakes, with a prominent erosion surface at -25 m marking the lake level. These lakes were finally flooded by the sea at 4 to 5 ka.

It is evident that, despite the research that has taken place in the Bras d'Or Lakes, more needs to be done before we have a good grasp of the sequence of events since deglaciation. Ongoing work by Stea and his co-workers (Stea, 2001) may soon provide new insights into the chronology of deglaciation. A significant advance in understanding of relative sea-level and lake-level changes may come sooner rather than later, for much of the lake has recently been mapped using multibeam bathymetry systems, and more surveys will take place in 2001 (Paul, 2001).

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COASTAL CHARACTER AND COASTAL BARRIER EVOLUTION IN THE BRAS D'OR LAKES, NOVA SCOTIA*

R. B. Taylor[1] and J. Shaw
Geological Survey of Canada Atlantic, Box 1006,
Dartmouth, Nova Scotia, B2Y 4A2

Little coastal geological research has been conducted in the Bras d'Or Lakes. This is the first re-examination of the coastline since the early 1900s. The 1234 km of coastline is extremely varied in relief and morphology. In terms of composition, 13.5% of the shores are rock, 1.6% are artificial or human-made, and the remainder is composed of unconsolidated sediment. It is estimated that 27% of the shores are along narrow channels and embayments which are sheltered from higher wave energy, but many are low lying which makes them more vulnerable to increased flooding as sea level rises. Many of the larger coastal barriers noted in the late 19th century remain. Using the oldest and most recent air photos and aerial video, changes at selected coastal barriers are assessed and a conceptual model for coastal barrier evolution is presented. Five natural phases of evolution were identified: (1) initiation, (2) growth, (3) establishment, (4) breakdown and (5) stranding or collapse. An alternative outcome for many barriers is artificial constraint (6), which is becoming more common as human activity increases in the Lakes. The criteria used in the model were applied to 80 of the largest coastal barriers to check its application as a guide for assessing shoreline stability. Thirty-nine percent of the barriers were identified in a building and established phase, and 44% in a breakdown to collapse phase. Field surveys are required to confirm the model and sample material for determining the age of coastal barriers and the duration of different phases of their evolution.

Très peu d'études géologiques sur les lacs Bras d'Or ont été effectuées jusqu'à présent. Cette étude constitue le premier ré-examen du littoral depuis le début du 19e siècle. Les 1234 km de littoral présentent une variété très riche sur le plan du relief et de la morphologie. En effet, 13,5 % des rivages sont constitués de roche, 1,6 % sont d'origine artificielle ou dus à l'intervention humaine, et tous les autres sont composés de sédiments non consolidés. On estime que 27 % des rivages se trouvent en bordure de canaux étroits et d'échancrures, ce qui les protège contre la forte énergie des vagues. Par contre, bon nombre d'entre eux sont de basse altitude, ce qui les rend plus vulnérables aux inondations lorsque le niveau de la mer s'élève. Plusieurs des grandes barrières littorales relevées à la fin du 19e siècle sont toujours présentes. Grâce à des photos aériennes d'hier et d'aujourd'hui et de vidéos aériennes, divers changements survenus à des barrières littorales sélectionnées ont pu être évalués et un modèle conceptuel d'évolution des barrières littorales a été proposé. Cinq phases naturelles d'évolution ont été identifiées : (1) initiation, (2) croissance, (3) établissement, (4) dégradation, et (5) effondrement. Une autre issue possible est la contrainte artificielle (6), qui devient de plus en plus fréquente avec une augmentation de l'activité humaine dans les lacs. Les critères utilisés dans le modèle ont été appliqués à 80 des plus imposantes barrières littorales pour vérifier leur efficacité en tant que guide d'évaluation de la stabilité du littoral. On a déterminé que trente-neuf pour cent des barrières se trouvaient dans une phase de construction et d'établissement, et 44% dans une phase de dégradation ou d'effondrement. Des études sur le terrain sont nécessaires pour confirmer le modèle et prélever des échantillons afin de déterminer l'âge des barrières littorales et la durée des différentes phases de leur évolution.

Introduction

The Bras d'Or Lakes are a semi-enclosed body of water located on Cape Breton Island, Nova Scotia. They consist of a series of elongated southwest to northeast trending basins (Fig 1) nestled between isolated hills and highlands to the north. The Lakes are connected to the Atlantic Ocean at three locations: Great Bras d'Or and Little

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* Geological Survey of Canada contribution 2001033

[1] Author to whom correspondence should be addressed

Bras d'Or Channels and through a pair of boat locks at the head of St. Peter's Inlet (Fig 1). It is estimated, using digital 1:50,000 Natural Resources Canada topographic maps, that the present length of the Bras d'Or Lakes' shoreline is 1234 km, including 285 km island shores (Sherin, 1998). These shores represent 14 % of the total length of the 8811 km of Nova Scotian coastline (Canada, 1972). The Lakes exhibit a wide variety of shore morphologies, but it was the remarkable assemblage of depositional features, primarily coastal barriers, that attracted the earliest coastal investigators. Initially Tarr (1898) and Woodman (1899) used these features to illustrate that waves, not currents, are the dominant force in their construction. Woodman (1899) went further and attempted to classify the different types of accumulation features (Table I). Goldthwait (1924) and Johnson (1925) used the features to illustrate their classic texts on New England and

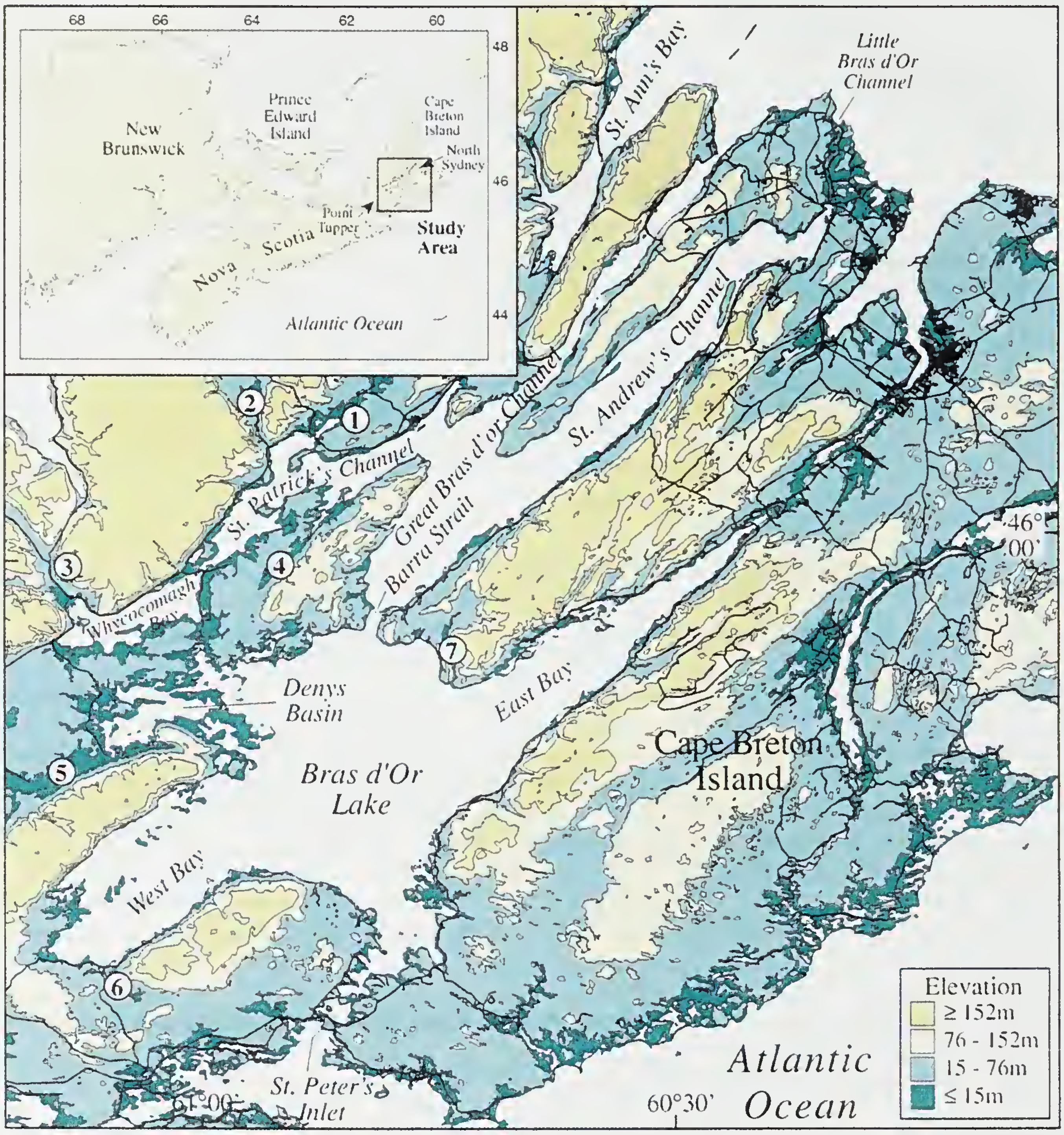


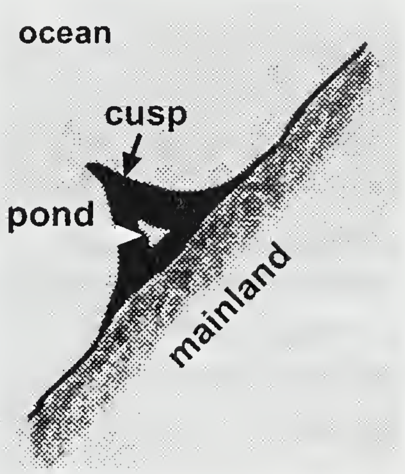
Fig 1 Location map and generalized topography of the study area illustrates the distribution of low lying and upland shores along the Bras d'Or Lakes. The topography is derived from digital 1:50,000 scale maps provided by Natural Resources Canada. Also labelled are the largest rivers emptying into the Bras d'Or Lakes including: 1) Baddeck, 2) Middle, 3) Skye, 4) Washabuck, 5) Denys, 6) Black and 7) Benacadie.

Atlantic Canadian coastlines. No coastal geology studies are known to have been completed in the Lakes since the early 1900s; however, there have been a number of other studies related to the coast. For example, Smith and Rushton (1964) described a number of coastal ponds or barachois in their study of potential sites for trout farming, and Grant (1994) discussed and used many shores to illustrate the glacial history of the region. Sailing guides, such as Cruising Nova Scotia (1997), provide a general description of the shores.

Table I Early classification of shore accumulation features in the Bras d'Or Lakes by Woodman (1899).

1) Cusp

(term replaced today by cuspate bar - a seaward pointing double crescentic bar formed by a single spit extending from shore and the turning back to shore or by two spits growing obliquely from the shore and converge to form a sharp cuspate form, American Geological Institute,1980).

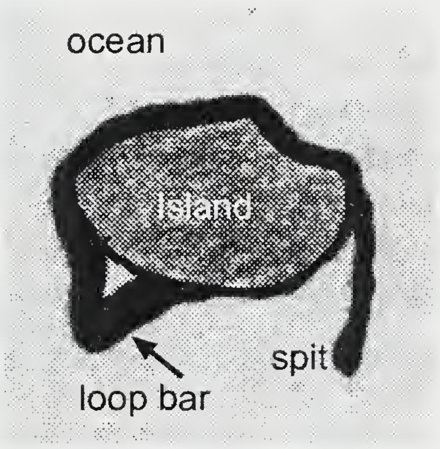


Types	**Examples**
- triangular shaped lagoons	
a) within a recurved spit	Beaver Cove, St. Andrew's Ch.
b) within two converging spits	Dougall Point, St. Andrew's Ch. (Fig 2b, locations 67, 66)

2) Loop bar

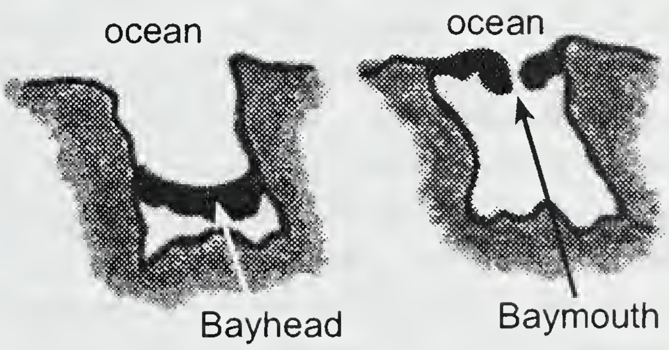
(synonym: Looped bar- a curved bar on the leeward side of an offshore island, undergoing wave erosion, formed by the union of two separate spits that have trailed off behind and joined together to form a loop that encloses or nearly encloses a body of water).

Example: Calf Island, West Bay.



3) Bay bar

(replaced today by terms which better signify the location of the deposit such as Baymouth or Bayhead barrier).

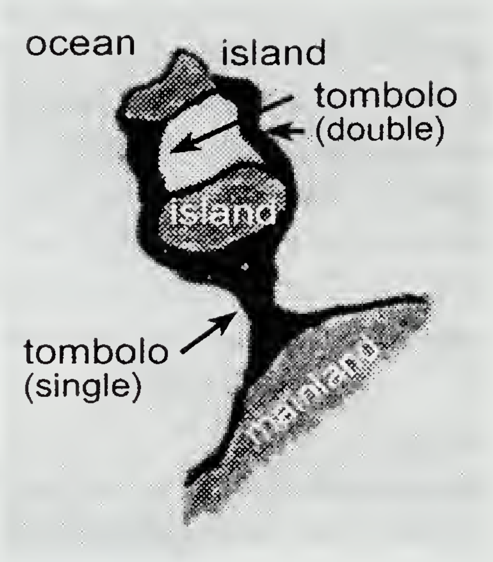


Types	**Examples**
- across mouth	Pellier Harbour,West Bay
- across head	West end St. Patrick's Channel
- damming and stream deflection	Lochan Fad, East Bay (Fig 2b, location 16)

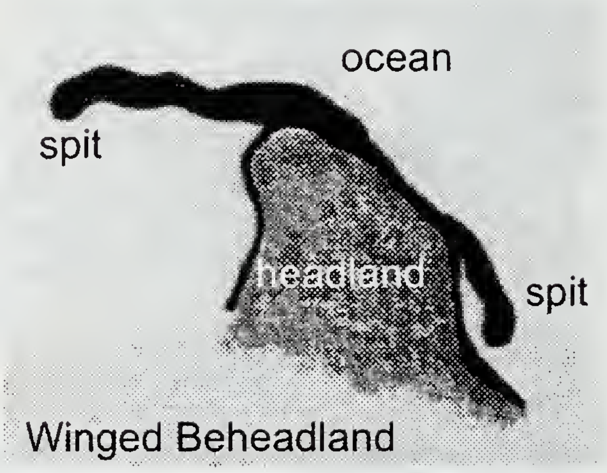
Table I (cont'd)

4) Tombolo
(a bar or barrier that connects an island with the mainland or with another island).

Types	**Examples**
-uncompleted	Pringle Island, West Bay
-completed -single	MacLeod Point, West Bay
-double	Indian Island, Whycocomagh Bay



5) Winged Beheadland
(synonym: winged headland -a headland having spits extending from both sides in opposite directions).
Example: Dhu Point, East Bay
(Fig 2b, location3)



6) Delta (river) **Example**: Middle River, St. Patrick's Channel;

7) Spit
(a short or long point or finger-like deposit extending from shore into a body of water).
Example: Lochmore, East Bay (Fig 2b, location 15)

In June 1996 an aerial video survey provided the first continuous view of these shores (Taylor and Frobel, 1998). On the basis of the video we present an overview of the range of shore types found along the Lakes and describe some of the processes that modify these shores. A few of the larger coastal barriers reveal more about recent and historical shoreline changes are then examined. From the physical changes observed, a conceptual model of natural coastal barrier evolution is introduced. Although much of the information presented is descriptive and based on previous research outside the Lakes, the intent is to stimulate interest in these shores and in the opportunities for further research, particularly on shoreline evolution. In this paper, coastal barriers refer to spits, barrier beaches and tombolos (Table I) which are backed by water including freshwater ponds, lagoons or wetlands.

Environmental Setting

The relief and physical character of the Bras d'Or Lakes basin are the product of successive episodes of crustal uplift, erosional planation, fluvial incision, partial submergence and most recently, glacial deposition and scouring (Grant, 1994). The

Lakes are carved out of younger, more easily eroded sedimentary rocks and the uplands consist of older, resistant, metamorphic and igneous rocks (Shaw et al., 2002). Grant (1988, 1994) and Stea et al. (1992) have mapped the surficial sediments of Cape Breton Island. In the Bras d'Or Lakes most of the shores are covered by a glacial till of unsorted debris 1-50 m thick which is finer over sedimentary rock lowlands and more bouldery in crystalline rock areas. Mounds or hills of thicker glacial deposits called drumlins form the islands in West and East Bays. These drumlins are part of a much larger field of drumlins which extends across southeastern Cape Breton Island.

There is geological evidence that sea level has been rising in the Lakes for thousands of years (Miller and Livingstone,1993; Lynch, 1995) resulting in significant modification and reshaping of the shores. Sea level changes in the Bras d'Or Lakes are currently being reassessed (Shaw et al., 2002). The best evidence of recent trends in sea level is derived from tide gauges at North Sydney and Point Tupper located just north and south of the Lakes (Fig 1, inset). The records show a rise of 38.7 and 43.1 cm/century, respectively (Shaw et al., 1993, Carrera et al., 1990).

In addition to longer term geological processes which control the physical setting, the availiability of sediment for beach development and changes in sea level, it is the tides, winds, waves, and sea ice that contribute to the changes in shoreline morphology. Tides cause changes of sea level to occur over periods of about 0.5 to 1 day. Tidal range is an estimated 0.18 m in the central part of the Lakes; in addition water levels can be raised by 0.5 m above the highest predicted tide by changes in atmospheric pressure, winds and sea level variations in the Gulf of St. Lawrence that occur over periods of several days to weeks (Petrie, 1999, Petrie and Bugden, 2002).

The Lakes are renowned for their extremely rough, choppy seas which can be generated rapidly by strong winds, funnelled along the channels by the surrounding uplands. Prevailing wind direction in summer is from the southwest and stronger winds from the north-northwest dominate the fall and winter (Parkes and Gray, 1992). Wave fetch, which is the distance over water that wind can generate waves, varies from 5 to just under 50 km. The only known recorded wave data from the Lakes were collected by Environment Canada using a wave rider buoy in the North Basin (just north of Barra Strait) from June to December 1992 and Bras d'Or Lake from June to November 1993. Wave periods were in the 2 to 4 second range and the significant wave heights (average of highest one-third of the waves) were roughly twice as large in Bras d'Or Lake as in North Basin during the periods of measurement (Petrie and Bugden, 2002). For example, for a 20 knot wind from the SW, the median significant wave height was close to 1 m in Bras d'Or Lake and only 0.5 m in the North Basin.

Based on about 30 years of sea ice data collected by Atmospheric Environment Service, Petrie and Bugden (2002) calculated weekly estimates of sea ice coverage. On average, coverage begins to develop in January although there are occasions when some ice forms in December. Ice cover begins to decrease rapidly in April and has generally disappeared by the first week in May. The most extensive sea ice cover is from late February to mid March south of Barra Strait, and slightly longer, until early April, north of Barra Strait. Ice floes from Cabot Strait can also enter Great Bras d'Or Channel as far as Seal Island during the spring (Parkes and Gray, 1992). Sea ice is often blown against the shores by strong winds causing large ice pile-ups in early and late winter. Many residents along the Lakes can provide accounts of sea ice grinding and piling against the shore, such as in 1990 when a large sheet of ice was blown southward against the shores of Middle Cape, Bras d'Or Lake (Fennell, 2001). No scientific accounts could be found which discussed the impacts of sea ice on coastal stability or infrastructure.

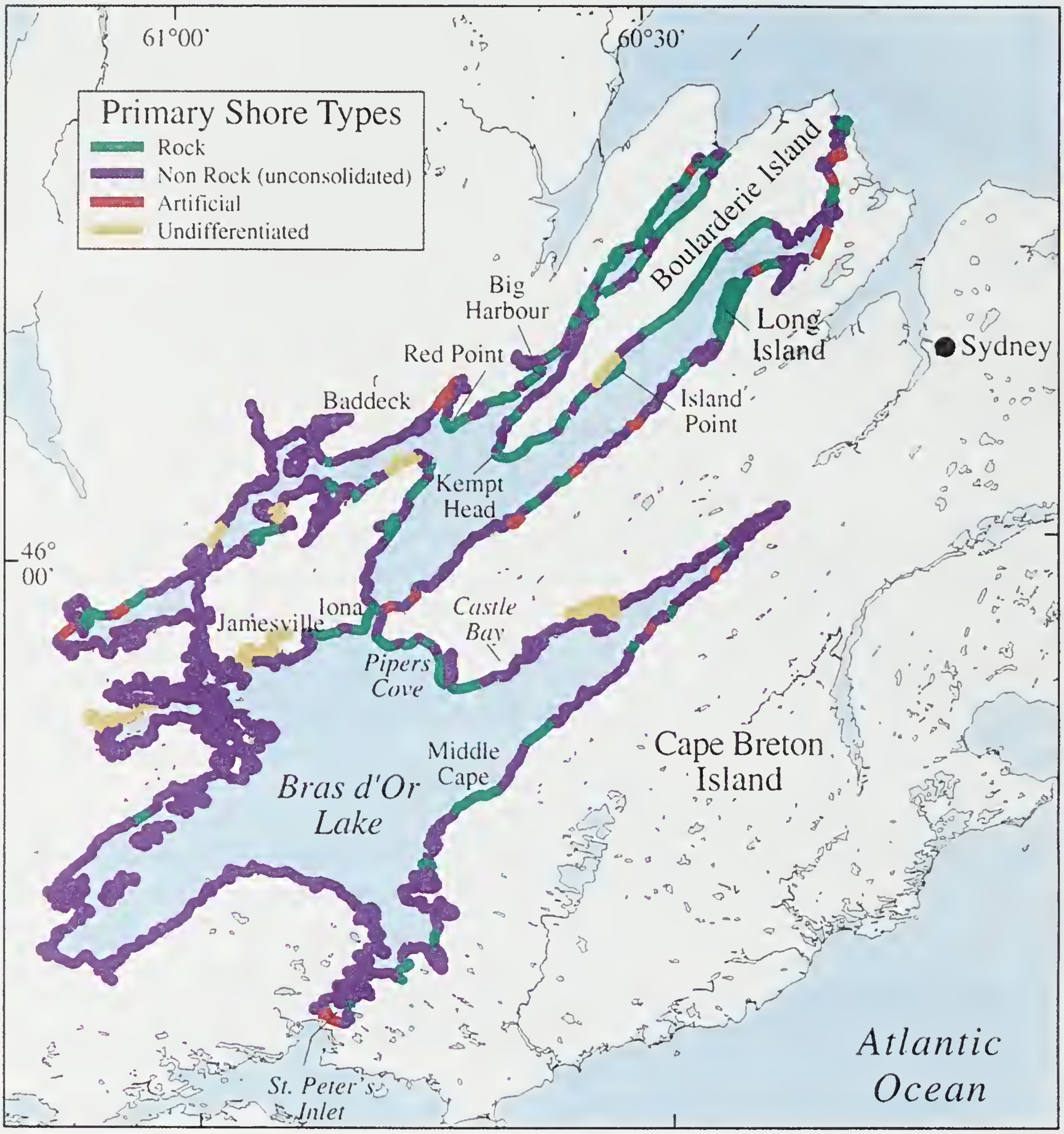


Fig 2a Distribution of primary shore types, rock, non-rock, and artificial in the Bras d'Or Lakes based on aerial video taken in 1996 (Taylor and Frobel, 1998). Shore types that could not be differentiated on the video are also shown. Only the more extensive areas of artificial shoreline, ie. road and railway beds, are illustrated. Photographs of typical shore types in the Lakes are provided in Fig 3 and 4.

Coastal Character

Coastal topography is extremely variable because of the complex underlying geology. Shores of 76 m or higher are found scattered throughout the Lakes (Fig 1), as are shores less than 15 m; however, low shores are more common in western parts of the Lakes. The highest shores reach over 300 m along the uplands of Great Bras d'Or Channel. Although some of the low shores are cliffed, such as the peninsula at Island Point on the north shore of St. Andrew's Channel, the low shores shown on Fig 1 indicate areas within the Lakes which would be most vulnerable to flooding as sea level continues to rise.

In terms of understanding coastal stability, it is useful to initially divide the coastline according to its composition. Using the aerial coastal video taken of the Lakes in 1996 (Taylor and Frobel, 1998), 13.5 % of the shores were identified as rock, and 77 % as non-rock or unconsolidated sediment (Table II, Figs 2a, 3b, 3c). Another 1.6 % of the shores were identified as artificial fill or human-made structures (Figs 2a, 3d). Roughly 8 % of the shores, mainly within the small embayments, were either not video taped or their composition could not be determined. These shores are thought to be unconsolidated.

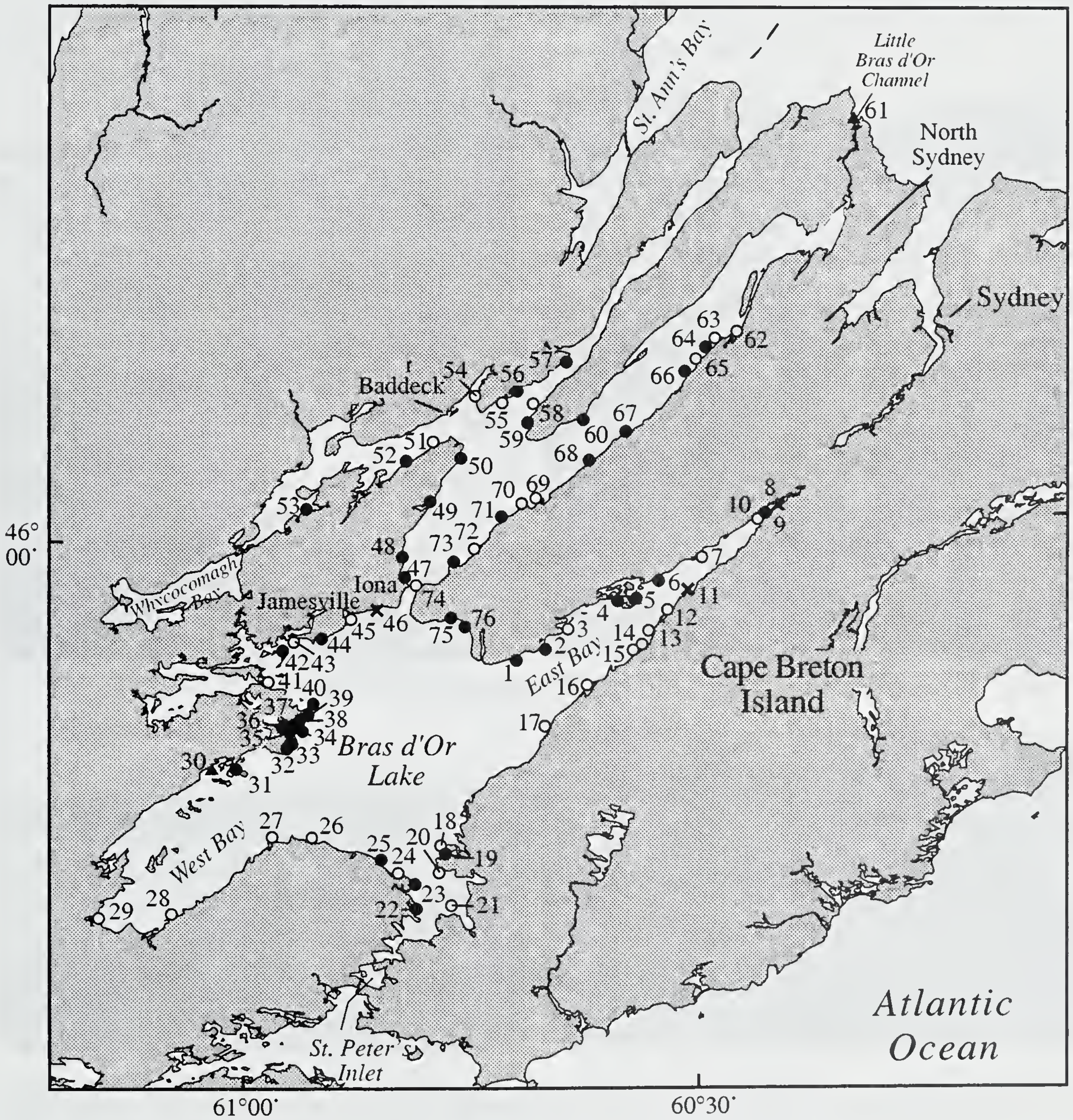


Fig 2b Locations of the largest coastal barriers in the Bras d'Or Lakes. The different location symbols, numbered, denote the present stage in the evolution of each barrier: building (triangle), stable (filled circle), degrading (open circle) and artificially constrained (x). More information about the physical characteristics of each barrier is included in Appendix.

Table II Distribution of rock and non-rock shores along the Bras d'Or Lakes and their percentage occurrence, identified from aerial video taken in 1996 (Taylor and Frobel, 1998).

Composition	Features	Coverage
Rock Shores	cliffed and non cliffed	13.5%
Non-Rock / Unconsolidated Shores	cliff with no beach	10.2%
	cliff with beach	10.5%
	fringing beach backed by land	17.5%
	beach backed by water (coastal barriers)	12.1%
	vegetated shores	26.8%
Artificial Fill		1.6%
Undifferentiated Shores		7.8%
	Total	100.0%

Rock Shores Rock shores are concentrated along the upland shores of Great Bras d'Or and St. Andrew's Channels, the north shore of Bras d'Or Lake and south shore of East Bay (Fig 1, 2a). The physical character of these shores is closely correlated with the local bedrock and its resistance to erosion. The highest backshores (76 m) exist in

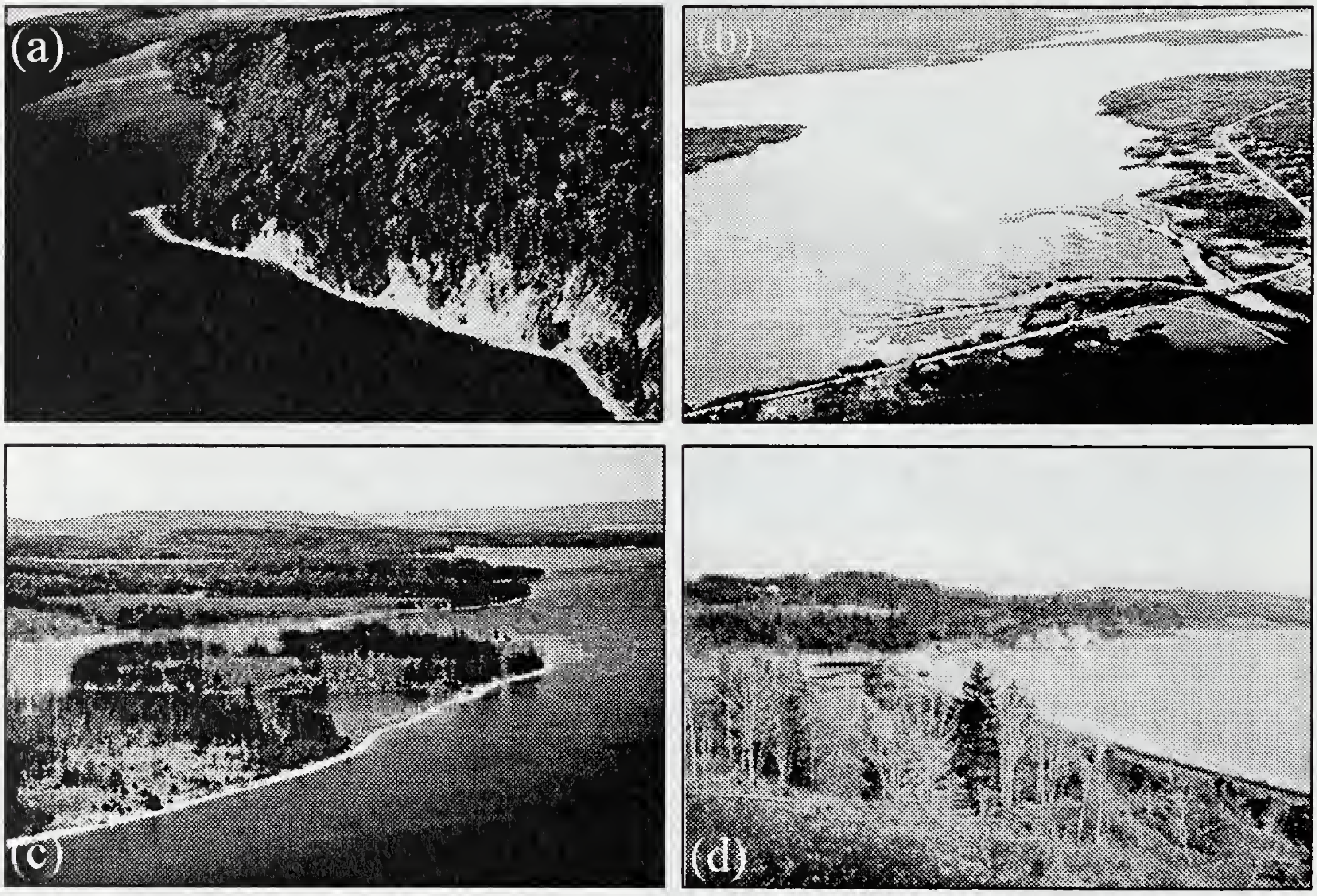


Fig 3 Photographs of select shore types in the Bras d'Or Lakes (a) Rock: 60 m high shores of Long Island, St. Andrew's Channel (June 25, 1996); (b) Non-rock: the Middle River delta, Nyanza Bay (Sept. 9, 1992), with extensive, partially submerged floodplain; (c) Non-rock: drumlin headlands and interconnecting barrier beaches representative of many low shores, Pellier Island (June 24, 1996) and (d) Artificial: fill added to build a railway line across an older barrier beach near Jamesville (Nov. 21, 2000).

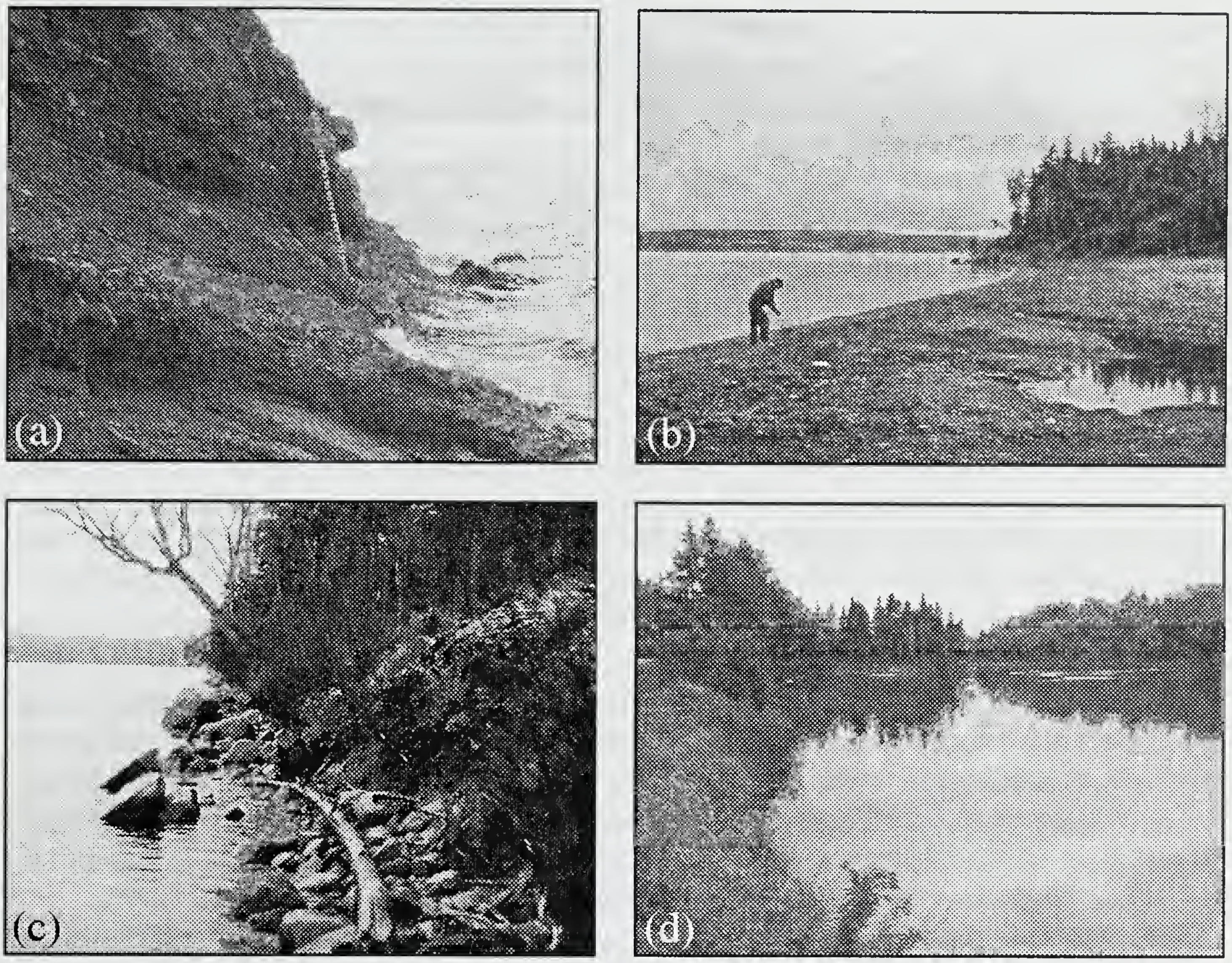


Fig 4 The composition of the shoreline varies from rock outcrop (a) such as well defined intertidal ramps cut into conglomerate rocks along Pipers Cove (Nov. 21, 2000); and unconsolidated shores such as (b) better sorted sand beaches at Grass Cove where the inlet was closed by waves from the NE or (c) poorly sorted boulder lag along outer Cow Bay, St. Patrick's Channel (Nov. 21, 2000) and (d) vegetated shores in the small embayments such as Campbells Cove, where fetch is insufficient to develop wave-built shore features (Sept. 7, 1998).

areas of the oldest and most resistant rocks: granites in the north and volcanics in the south. The most notable granite cliffs are at Red Point, near Baddeck. Long Island, St. Andrew's Channel which consists of older Proterozoic non-granitic rocks is fringed by 60 m high, talus banked cliffs (Figs 2a, 3a). The volcanic rock shores, along East Bay and St. Peter's Inlet are mostly low lying, except for the upland coast near Middle Cape (Fig 2a). Along much of these shores the bedrock is masked by glacial deposits but when exposed, rugged, irregular outcrops trap sediment and form small pocket beaches.

The best examples of younger clastic rock cliffs are along Pipers Cove, Bras d'Or Lake where well defined shore ramps (Figs 2a, 4a) are backed by cliffs of 15 to 20 m. Both the ramps and cliffs are cut in seaward dipping conglomerate rock, topped by glacial deposits. Near Benacadie Point the bedrock is similar but shore ramps do not form because of a change in bedding orientation. The most common shore cliffs observed in the Lakes are usually less than 15 m elevation, formed in Windsor Group rocks consisting of gypsum, anhydrite, sandstone, limestone or shale. Exposures of gypsum anhydrite form distinctive white shore cliffs along several shores including between

Jamesville and Iona, Bras d'Or Lake (Figs 2a, 3d), along Island Point, St. Andrew's Channel, and Big Harbour, Great Bras d' Or Channel. Solutional weathering of the upper slopes and sink holes are associated with these outcrops. Well developed shore cliffs composed of Horton group rocks mark Kempt Head at the south end of Boularderie Island (Fig 2a) and low cliffs constrain Little Bras d'Or Channel. In terms of shoreline evolution, high rock shores limit lake expansion and rock outcrops provide anchor points and a source of sediment for the large depositional shore features.

Non-rock shores Despite the presence of higher inland terrain, much of the shoreline is low lying and composed of unconsolidated sediment of mainly glacial origin. The non-rock shores can be further broken down into five subdivisions on the basis of their morphology and beach development (Table II). Thicker glacial deposits form coastal headlands and shore cliffs which are important sources of sediment and anchors for beach development. Roughly 20% of the shores were cliffed, with half being fronted by mixed sediment beaches (Fig 3c). Many of the cliffed shores are erosional scarps less than 5 m high. The higher shore cliffs are eroded drumlins or localised cliff sections composed of multiple glacial tills or other deposits such as the 30 m high cliffs near Castle Bay, East Bay.

Forty percent of the shores are beaches of which 12% are defined as coastal barriers (Figs 2b, 3c, 4b) backed by water. Many beaches appear at first glance to be sandy but most contain a mixture of sand to cobble size material and in many cases the presence of dune vegetation is associated with both sand and very fine pebble. Coastal barriers 250 m or longer are located numerically on Fig 2b and described in Appendix 1. Several are discussed in more detail in the remainder of the paper.

Another 27% of the shores, mainly within the embayments exhibit little evidence of wave-built beach features, and vegetation extends to the waterline. Along the north shore of St. Patrick's Channel many of the forested and grassed slopes are fringed by a boulder lag (Fig 4c) formed by the winnowing of glacial deposits by water motion. Vegetated shores exist mainly within small, or narrow embayments (Fig 4d). The largest extent of wetland and marsh shores are within Denys Basin, and head of Whycocomagh Bay. Extensive wetland and marsh vegetation cover the floodplains and deltas at the mouths of the Skye, Middle, Baddeck, Denys, Washabuck, Black and Benacadie Rivers (Figs 1, 3b). The deltas extend beyond the main shoreline at the Skye, Middle and Baddeck Rivers and exist well back of the main shoreline at the Denys, Black and Benacadie Rivers. Drowning of the river floodplains may be an indicator of rising sea level, however research into the dynamics and sedimentation of these rivers is required to confirm it.

Artificial shores include human-built structures such as wharves, jetties and breakwalls, and fill along road and railway lines (Fig 2a, 3d). These deposits or structures are designed to protect the shores from erosion and therefore are more resistant to change. The scale of the map in Fig 2a precludes showing individual shore structures so only the more extensive areas of fill are shown.

Coastal Barriers: Evidence of Coastal Changes

Much has been written recently regarding the evolution of coarse grained beach deposits found along the outer coast of Nova Scotia (Boyd et al., 1987; Forbes and Taylor, 1987; Forbes et al. 1990, 1995; Carter et al., 1990; and Orford et al., 1991). Similar shore features, such as spits, barrier beaches and tombolos are found in the Bras d'Or Lakes (Fig 2b). Their horizontal extent is comparable to features observed on the

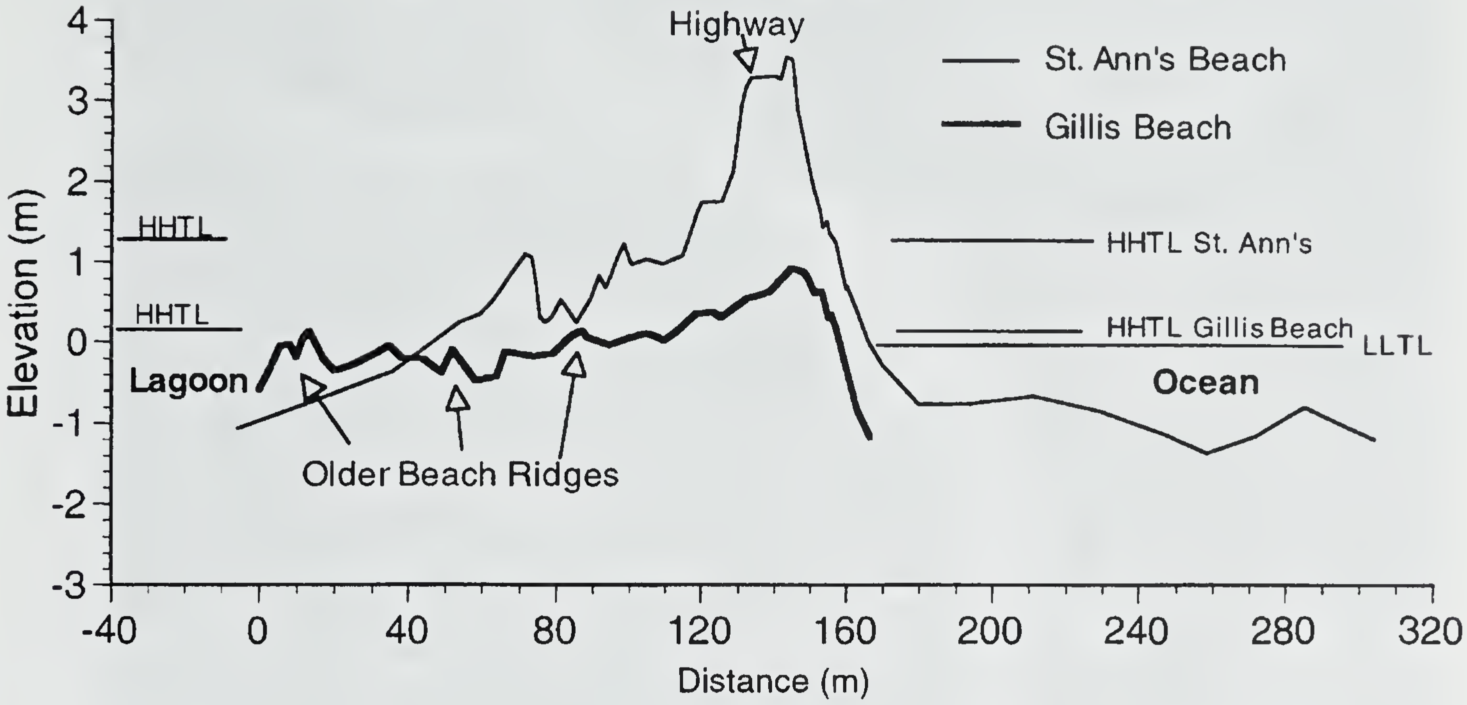


Fig 5 Cross-shore profiles of coastal barriers from St. Ann's Bay, on the outer Nova Scotia coast (Fig 1), and Gillis Beach, Bras d'Or Lake, illustrate the difference in vertical extent of beach features in the two areas. The large tidal range is 1.34 m at St. Ann's (Canadian Hydrogeographic Service, 2000) and 0.18 m in Bras d'Or Lake (Petrie and Bugden, 2002). The difference between the seaward beach crest elevations is 2.3 m. Both barriers are backed by submerged beach ridges. Vertical datum for both beaches is set at lower low tide level (LLTL). HHTL is higher high tide level. (St. Ann's Beach survey data are courtesy of D.L. Forbes and D. Frobel, GSCA).

Atlantic coast of Nova Scotia but their vertical scale is much smaller because of significant differences in the magnitude of processes affecting them (Fig 5). A smaller tidal range, lower wave energy and longer duration of sea ice exist in the Lakes.

In his early description of Bras d'Or Lakes shores, Woodman (1899) provided a preliminary classification of coastal depositional features based primarily on morphology (Table I). Many of the names he used to describe the features have changed and evolved, as has our understanding about the evolution and linkage of different shore features. All of the depositional features cited by Woodman (1899), including those listed in Table I, are still present in the Lakes 100 years later (Fig 2b), but some have changed significantly. Even within the same geographic area, where the shores were subject to similar wave energy, significant differences in shoreline change were observed (Fig 6).

Very little research has been completed on coastal barriers within the Lakes and much field work is required before a detailed chronology of their evolution can be achieved. Nevertheless, the number, sequence and arrangement of beach ridges within each depositional complex reveal much about its recent evolution. For example, multiple beach ridges signify sediment abundance and shoreline progradation. Low, discontinuous ridges reveal a scarcity of sediment and shoreline degradation. Furthermore we can differentiate between drift-aligned barriers, where waves strike the coast at an oblique angle moving sediment alongshore, and swash-aligned systems where waves strike more directly onshore and move sediment onshore and offshore. Swash-aligned barriers tend to be more concave in shape and build across embayments. Drift-aligned barriers are more straight to convex in shape and extend alongshore with

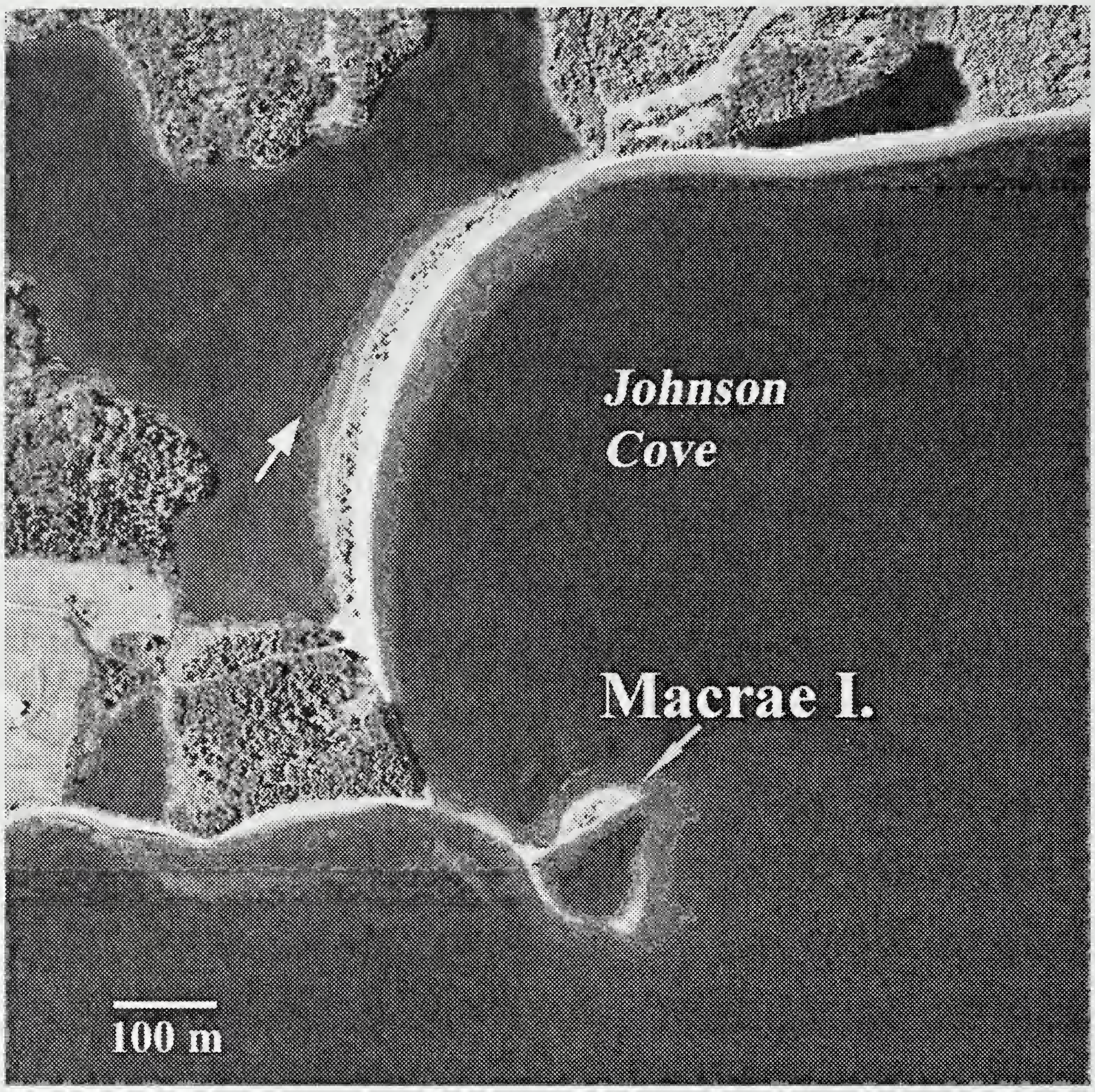


Fig 6 Aerial view of Johnson Cove showing contrasting rates of shoreline change within a small area. Despite similar processes reworking these shores, the coastal barriers at Macrae Island have eroded and deteriorated faster than the larger coastal barrier developed across the head of Johnson Cove. These barriers are made up of multiple beach ridges (marked by trees and arrow). The rapid changes at Macrae Island result from the loss of the outer island which anchored and supplied sediment to the barrier beaches in its lee (air photo 98311-183, June 29, 1998).

multiple ridges near their distal end. Small cuspate nodes can form along drift-aligned barriers if sediment moves alongshore in pulses (Carter et al., 1987; Carter and Orford, 1991). A large coastal barrier complex can include both swash- and drift-aligned components. In the Bras d'Or Lakes, barrier beaches can extend >1 km in length. Beach-ridge plains are usually less than 350 m in length; however in a few cases, multiple beach ridges extend to 700 m, such as along East Bay and Bras d'Or Lake (Fig 2b locations 4, 44). The larger features exist in areas of longer wave fetch. Two examples, Gillis Beach and Dhu Point, (Fig 2b, locations 45, 3) are used to illustrate how beach ridge morphology can be used to interpret shoreline evolution (Figs 7, 8).

Gillis Beach, Bras d'Or Lake Gillis Beach is located on the north shore of Bras d' Or Lake near Jamesville (Fig 2b, location 45). It extends 700 m alongshore and encloses

Gillis Pond (Fig 7a). It is primarily a swash-aligned barrier consisting of multiple beach ridges which are 160 m wide at its northern end and a smaller, 6 m wide drift-aligned ridge along its southern part. Water is presently flowing in and out of Gillis Pond across the low southern beach ridge. In 1939 a narrow inlet cut through the barrier south of the multiple ridges. By 1998 the inlet had shifted farther north and despite attempts to keep it open, it has naturally infilled. A survey was completed across the multiple beach ridges (Fig 7b) in the year 2000. Beach ridge elevation increases seaward from 0.02 m below water level at the most landward ridge to 0.93 m at the most seaward ridge. The most landward ridges are submerged and covered by wetland vegetation and soft mud varying in thickness from less than 0.1 to 0.5 m. The presence of tree stumps on the submerged ridges (Fig 7b), similar to those reported at a number of other sites by Grant (1994), provides evidence of rising water level. The most seaward beach ridge is higher and composed of wave overwashed sand and granule material which suggests the beach is building as it is pushed landward. If one assumes that the tidal range has not changed and beach ridges were built to similar elevations in the past as they are now, then the landward ridges would have been built when sea level was 0.9 to 1.0 m lower. Since sea level has risen at an estimated 0.3 m / century, a minimum age for this complex would be 300 years.

It is not known when the barrier beach closed off Gillis Pond. The morphology of the beach ridges suggests they were initially built by sediment moving mainly from north to south and later became more swash-aligned as sediment accumulated. Today, much of the north shore consists of shore cliffs of gypsum/anhydrite (Fig 3d) and boulder armour along the base of the railway. Therefore, any major sediment supply from the north has been depleted. Bathymetric chart 4279 (Canadian Hydrographic Service, 1991) shows a shoal farther offshore in water depths of 3 to 5 m extending southward across the front of Gillis Pond. It is postulated that this ridge represents the foundation of a former spit that would have extended at least 1 m above sea level. It broke apart and the bulk of its sediment shifted onshore to Gillis Beach. On the basis of a sea level rise of 0.3 m /century, the submerged beach complex would have existed 1000 to 1300 years ago. Field sampling and surveys are needed to confirm this hypothesis.

Dhu Point, East Bay Dhu Point (Fig 2b, location 3) was one of the largest drift-aligned shore features in the Lakes. In 1939 it extended 1600 m alongshore and may have extended even farther to Christmas Island (Fig 8a). Most spits at present including Dhu Point are less than 600 m in length. In 1939 Dhu Point consisted of three main shore segments, a beach ridge plain at its proximal end (Fig 8a, i) a low narrow, partially submerged central part (ii) and a distal end (iii) which consisted of several recurved ridges. On the basis of beach ridge morphology, it appears the beach ridge plain was supplied sediment from the headland and high shore cliffs just west of Dhu Point (Fig 8a, iv). They are composed of multiple tills and sandy deltaic deposits (Grant, 1994). It is not known when spit growth began. By 1939 the beach ridge plain had been trimmed along its western shore and the central part of the spit had become very low and overwashed by waves which transported increased amounts of sediment into the lagoon. Consequently, there was less sediment available to supply the distal end of the spit and by 1998 most of the spit had become overwashed and drowned, leaving only a few small parts above high tide (Fig 8b). Sediment stored in the beach ridge plain now is being eroded to build a new spit.

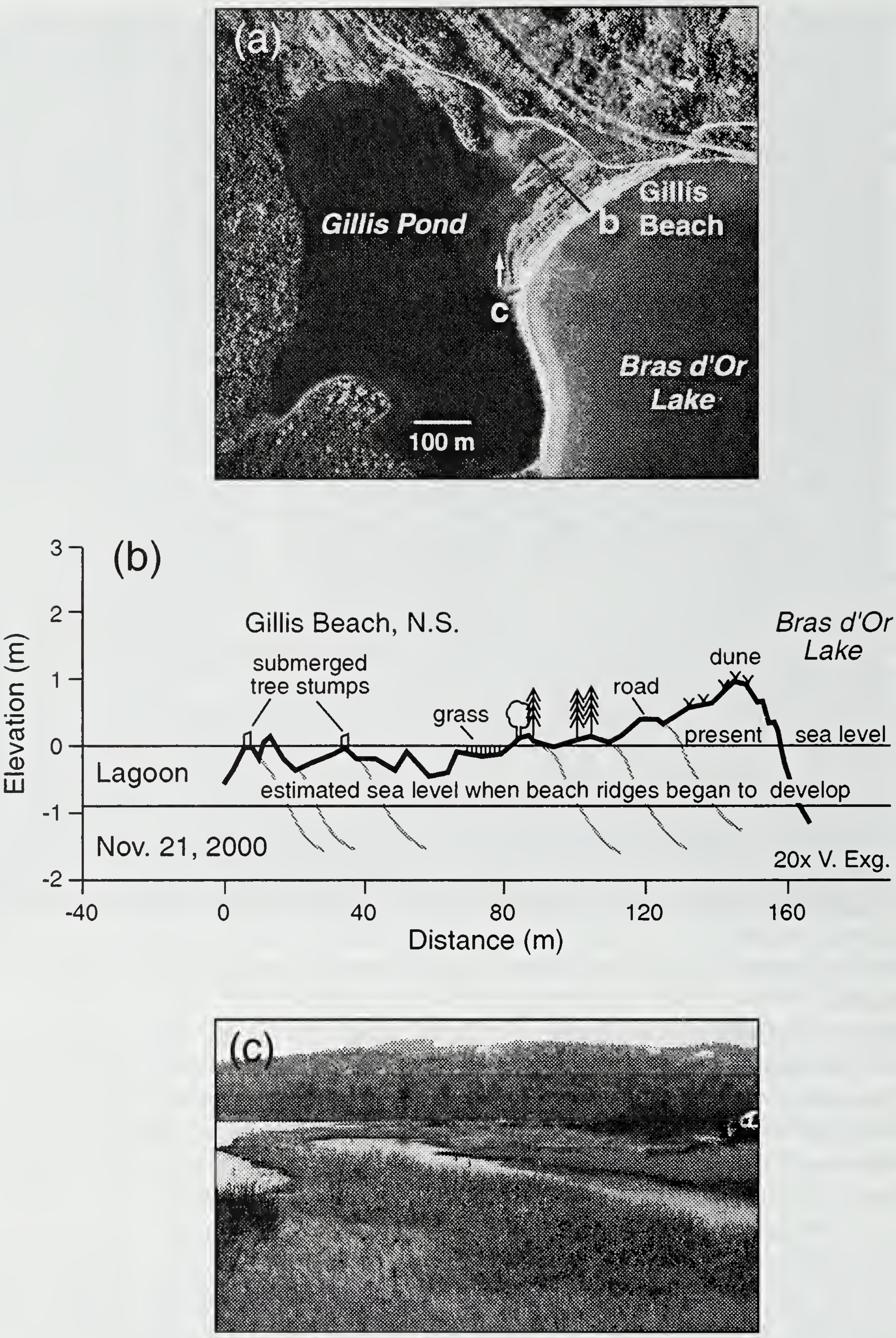


Fig 7 Gillis Beach, Bras d'Or Lake (a) aerial view (air photo 98301-212, June 11, 1998) of multiple beach ridges at north end of Gillis Beach and location of the cross-shore survey shown in (b) which illustrates the seaward rise in elevation of the beach ridge crests. Vertical datum is water level which approximated low tide level. Old tree stumps on the submerged back barrier ridges (c) provide evidence of a rising sea level as does the higher present beach crest which is aggrading by wave overwash. Based on a rate of sea level rise of 0.30 m/century an estimated minimum age of this beach complex is 300 years.

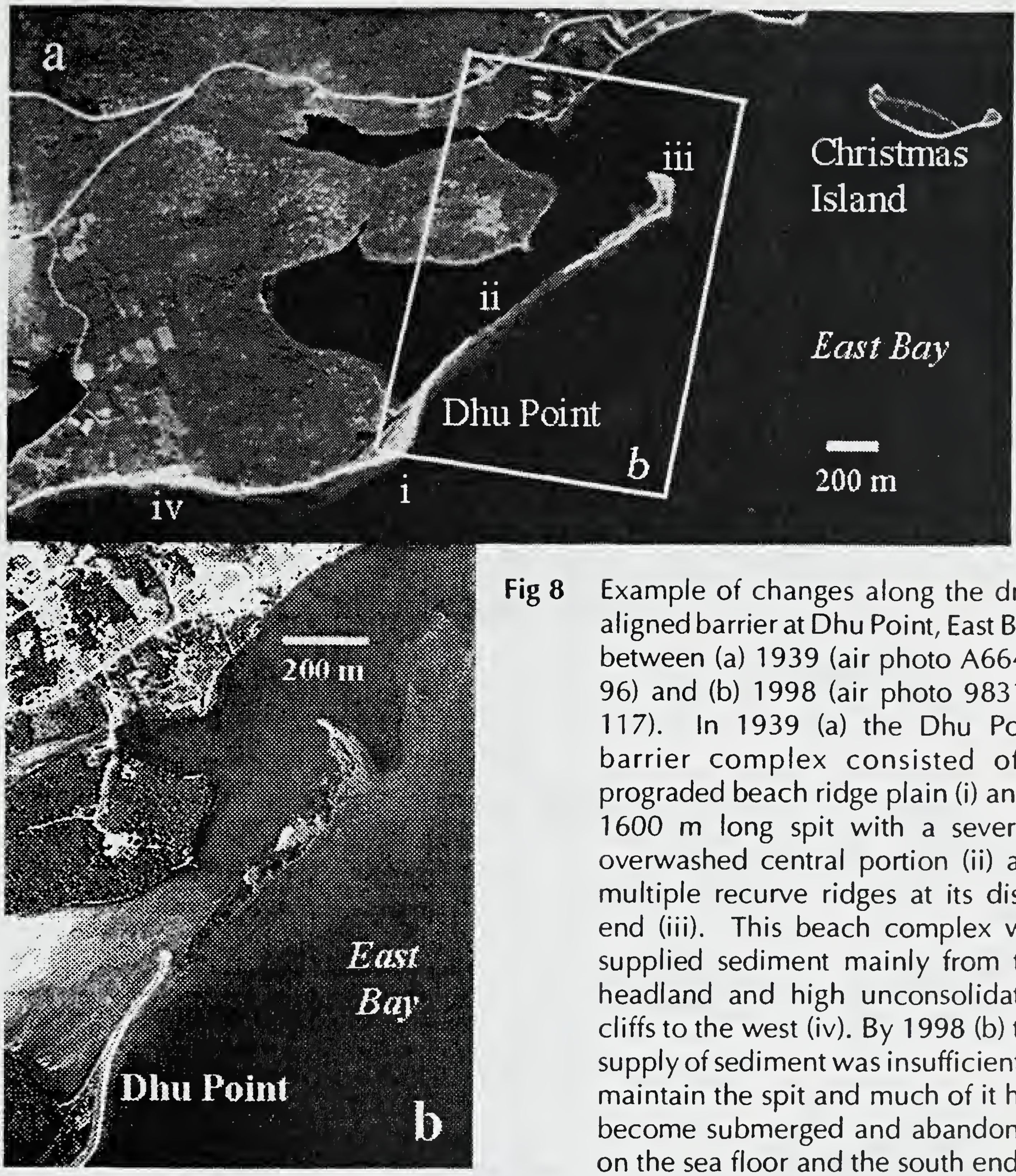


Fig 8 Example of changes along the drift-aligned barrier at Dhu Point, East Bay, between (a) 1939 (air photo A6649-96) and (b) 1998 (air photo 98315-117). In 1939 (a) the Dhu Point barrier complex consisted of a prograded beach ridge plain (i) and a 1600 m long spit with a severely overwashed central portion (ii) and multiple recurve ridges at its distal end (iii). This beach complex was supplied sediment mainly from the headland and high unconsolidated cliffs to the west (iv). By 1998 (b) the supply of sediment was insufficient to maintain the spit and much of it had become submerged and abandoned on the sea floor and the south end of the spit was becoming thinner and curling landward.

Conceptual Model of Coastal Barrier Evolution

Although very little research has been completed on coastal features within the Bras d'Or Lakes, we can build on previous research of coastal barriers from the nearby Atlantic coast to enhance our understanding of coastal evolution within the Lakes. In a number of recent investigations, researchers observed that coarse-grained barriers experience long intervals of slow change, punctuated by short periods of rapid reorganization (Orford et al., 1991 and Forbes et al., 1990, 1995). They further observed that the response to external forcing factors such as rising sea level, wave energy and varying sediment supply varies locally depending on the intrinsic characteristics of each barrier system such as its present condition, i.e. erosional or

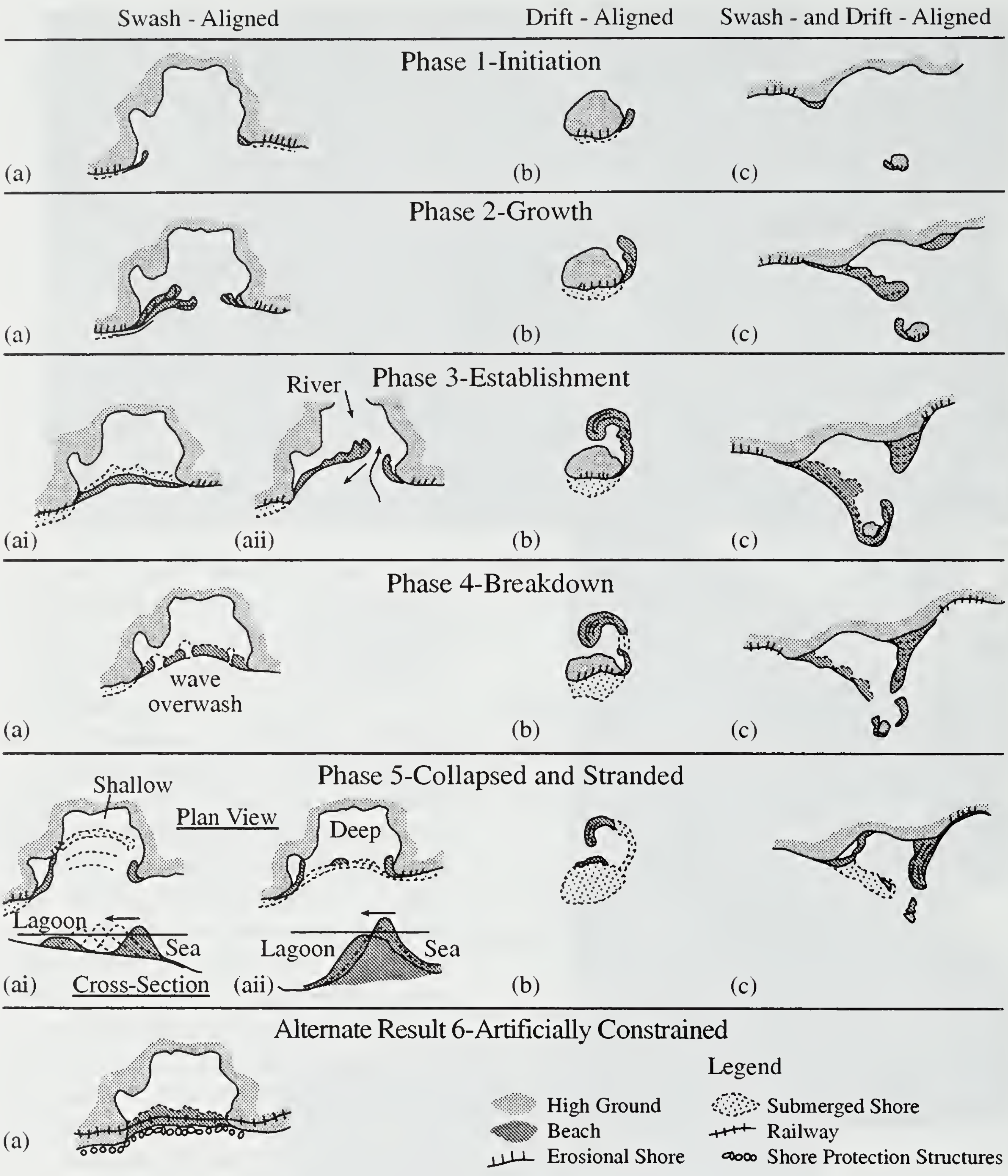


Fig 9 Conceptual model for evolution of (a) swash-aligned, (b) drift-aligned and (c) more complex swash- and drift-aligned coastal barriers in the Bras d'Or Lakes. The model is refined from the models of Orford et al. (1991) and Forbes et al. (1995) for gravel barriers along the outer coast of Nova Scotia. Examples for phases 1 to 5 are shown for the three barrier types and one example of a barrier artificially constrained by human activities - an alternate outcome, 6 is shown. The letters (a to c) are used for linking the text to the diagram.

depositional, its ability to recycle sediment alongshore or offshore-onshore, and accomodation space for its growth and development. Accomodation space is a function of water depth and distance between headlands or other anchor points. The same authors developed an evolutionary framework for coastal barriers within a transgressive (rising sea level) setting. Within the model, individual barrier structures are initiated, become established and breakdown before the cycle resumes. The model differentiates between drift-and swash-aligned barrier systems but recognises that larger coastal barriers can have components of both and that over time a barrier may switch from a drift- to a swash-aligned system and vice versa.

Table III Phases of Coastal Barrier Evolution in the Bras d'Or Lakes.

Phase	Defining Criteria	
1	Initiation	Short extension offshore of variable shape but most often pointed, at sharp break in shore orientation, little or no backbarrier lagoon; may or may not be vegetated.
2	Growth	Moderate to long extension offshore; straight, undulating or slightly curved; continuous beach crest with no major cuts by overwash; may consist of multiple shore parallel beach ridges in proximal to central part, or one or more recurve ridges and/or a lower bulge at the distal end; backshore vegetation more mature at proximal end, grasses and bushes more common.
3	Establishment	Moderate to long, wide, continuous barrier with smooth, natural curves in planform; usually consists of multiple beach ridges or a wide single beach ridge and backshore dune; both ends joined to other shores or one end joined and wide multiple beach ridges recurved back toward the barrier near distal end; can have a tidal inlet; cross shore gradation in vegetation, e.g. from grass to trees.
4	Breakdown	Marked differences in longshore physical character-discontinuous or segmented barrier. Early stage: broken by wave overwash channels which extend across barrier, or narrow continuous crest with washover lobes extending into backbarrier lagoon; significant variations in barrier width - very narrow segments often the proximal end(s) and distal end may still exhibit growth. Late Stage : one or more barrier segments very low or totally submerged but still intact underwater; small recurve ridges develop at point(s) where barrier becomes submerged; inlets have widened or new ones established; where multiple beach ridges exist, the seaward ridge is highest and aggrading with wave overwash deposits; vegetation patchy and trees dying in low backshore.
5	Collapsed /Stranded	Narrow, irregular and segmented , thin strips of exposed beach along landward side of extensive shoal; long segments submerged or parts detached; where lagoon is shallow, parts of original barrier migrate landward and/ or recurve against main shoreline, where lagoon is deep, barrier is totally submerged and intact or central part is submerged and both ends recurve onto main shore forming smaller barrier; initiation

Table III (cont'd)

		of new barrier often observed at proximal end; very patchy or no vegetation.
Alternate Forced Outcome		
6	Artificially Constrained	Barrier dominated by straight lines and irregular planform; human-made structures, e.g. buildings, railways, shore protection dominate backshore and/or waterline; tidal inlets constrained or anchored by structures, natural beach ridges or dunes smeared or masked by artificial fill, and manicured backshore vegetation which alters natural water retention and drainage.

Examples from the Bras d'Or Lakes were selected from the earliest (1930s) and the most recent (1998) vertical aerial photographs to illustrate and refine this evolutionary model (Fig 9). A significant benefit of investigating shoreline evolution in the Lakes is that many of the older submerged features are better preserved and more visible on vertical air photos than along the open ocean coast where they are modified by higher energy waves and are less identifiable. Criteria used to identify the phases of barrier evolution in the Lakes are listed in Table III.

Phase 1-Initiation Barriers may be initiated by waves transporting sediment from

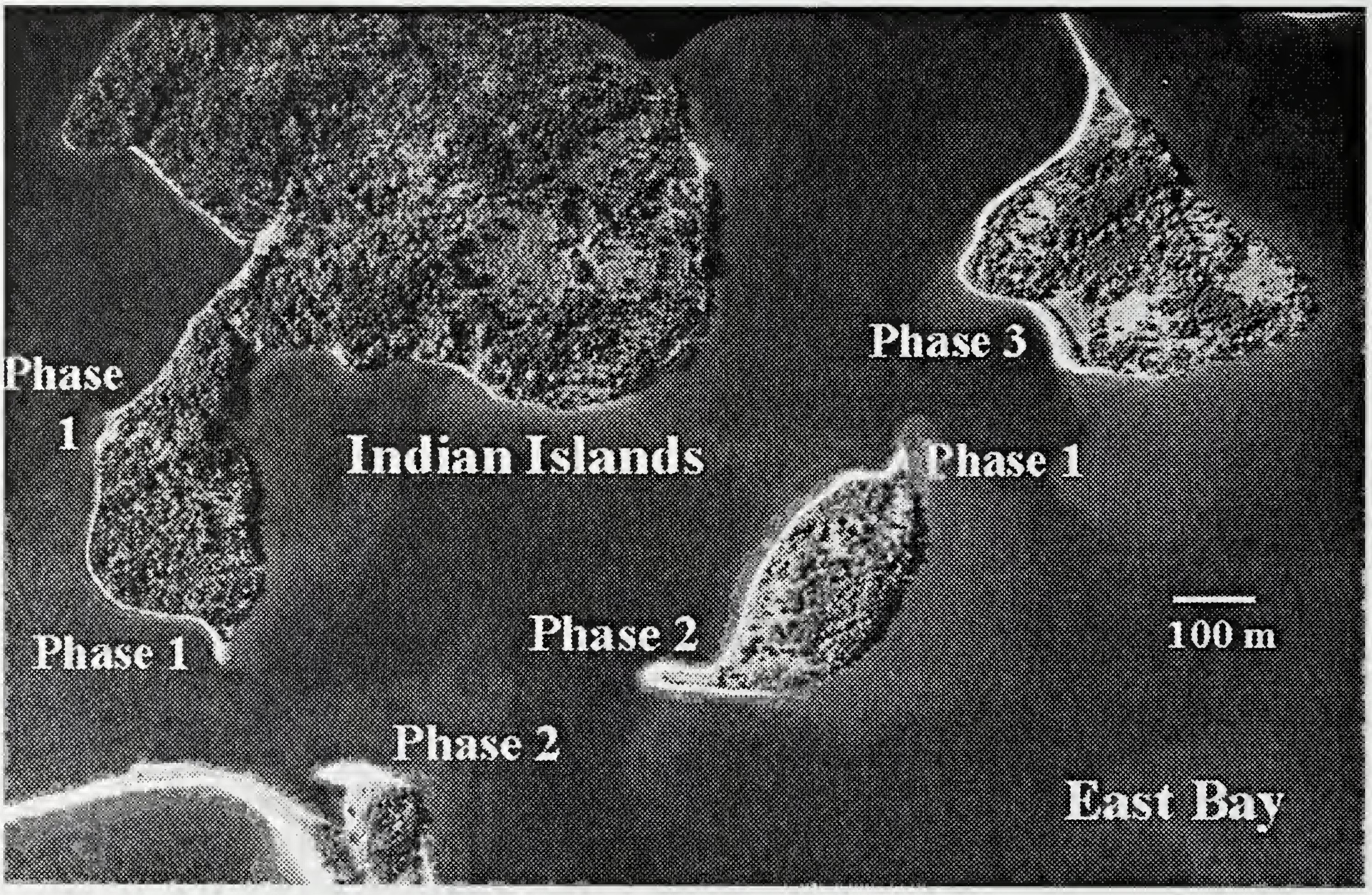


Fig 10 Aerial view (photo 98301-237) of the Indian Islands, East Bay where several shore features are being initiated (phase 1). Drift-aligned shore features are initiated at sharp changes in shoreline orientation, they are small and pointed or cusp shaped. If sediment supply continues the features become extended (phase 2) as shown by two examples in this photograph. The barrier marked as phase 3 is smaller in extent than most listed in Appendix but it has multiple beach ridges, a stable smooth outline and consists of a cross-shore gradation in vegetation.

point or line sediment sources, most often shore cliffs and develop at sites of significant change in shoreline configuration (Fig. 9, phase 1a). Initially, sediment is transported alongshore forming spits or forelands (Fig 10) but with further growth these features can become swash-aligned barriers depending on shoreline geometry and local bathymetry.

Phase 2-Growth The growth of a barrier depends on sediment supply and water depths. For example, where the adjacent waters are shallow, sediment can quickly accumulate and extend farther away from the source (Fig. 9, phase 2a, c); whereas if deeper water exists, the accumulation feature will generally be forced to extend close to shore, toward the lee of the source (Fig 9, phase 2b; Fig 10,11). A barrier may extend in width as multiple beach ridges (Fig 9, phase 2a), and /or in length as a series of recurve ridges or both (Fig 9, phase 2b).

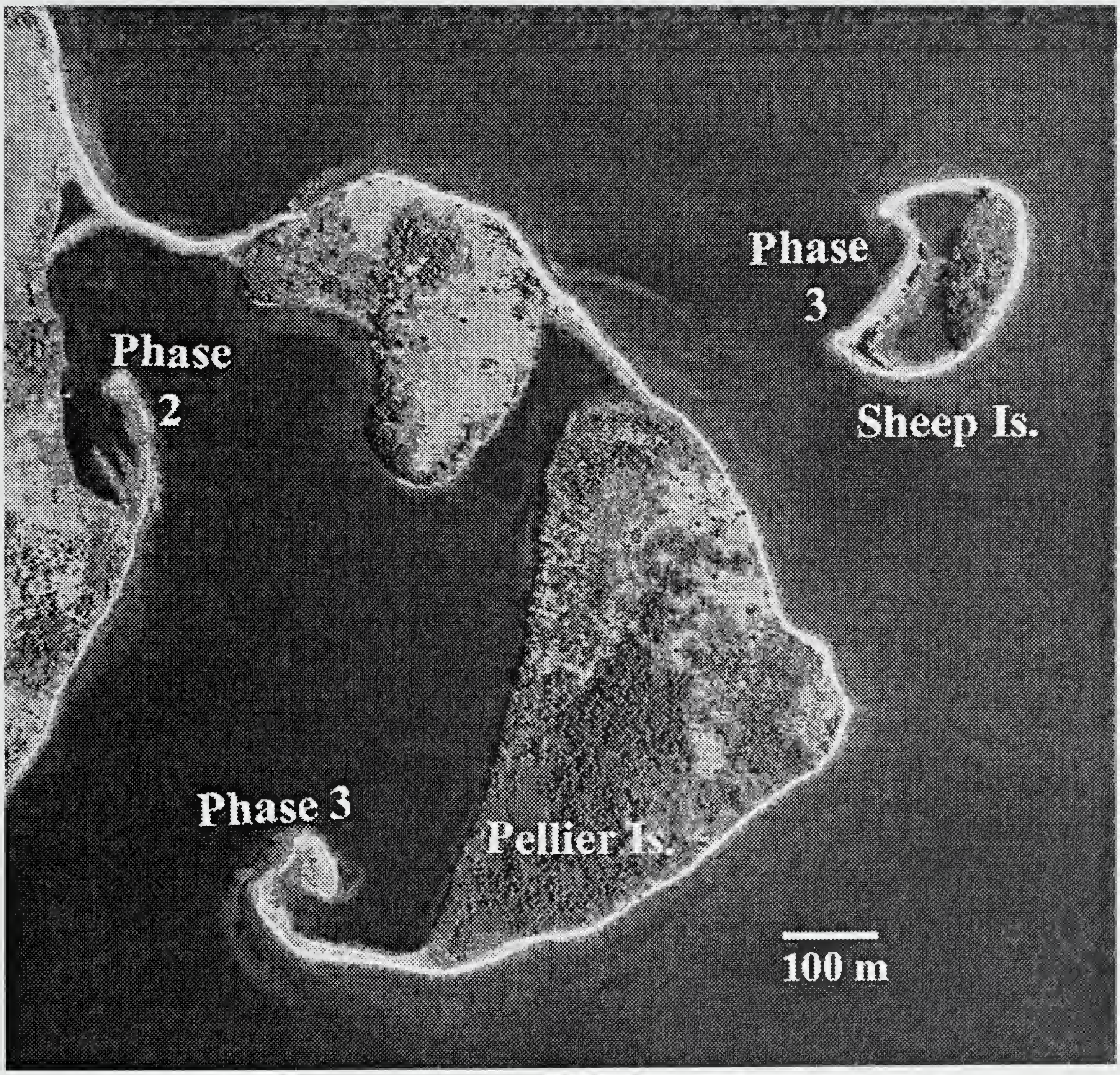


Fig 11 Aerial view (photo 98320-49) of Pellier and Sheep Islands at the entrance to Malagawatch Harbour. The spit to the left with multiple ridges appears to be still growing and is in phase 2 despite some erosion of its proximal end. The two features labelled as phase 3 have become more established. Growth of the spit on Pellier Island has been arrested and it has hooked back upon itself and attained phase 3. Two spits have joined to form a double loop structure in the lee of Sheep Island where a wider beach with multiple ridges and connection at both ends provides more stability; therefore, it is considered in phase 3.

Phase 3-Establishment If sediment supply is sufficient, the spit can attach to an adjacent shore, outcrop, or island and become a better stabilized barrier beach or tombolo (Fig 9, phase 3, Figs 10,11,12, Appendix). Established barriers are often covered by a well defined gradation in cross- shore vegetation varying from dune grass to trees. The seaward crest or duneline is continuous and fairly similar alongshore. Once a barrier is established, if sediment continues to be supplied, beach growth may continue over several centuries or millenia. Where sea level is rising, the seaward ridges will be built higher than the older landward ones which were built at a time of lower sea level (Fig 5,7b). In a drift-aligned setting, continued sediment supply can result in sediment spill over into the next shoreline compartment and the growth of a new barrier, e.g. Dhu Point, East Bay (Fig 8a,9, phase 3c). Another situation commonly observed in the Bras d'Or Lakes is where a spit extends behind its anchor and point source to form a loop structure, e.g. Sheep Island, Malagawatch Harbour (Fig 11). In some instances paired loop structures may develop, and in other cases, two flanking spits may join to form a single spit or tombolo behind the island (Macrae Island, Fig 6). Water depth, the size of the island and wave dynamics control the growth pattern. Established barriers may exhibit erosional features after storms but generally have the capability to recover and rebuild.

Phase 4-Breakdown As sediment supply diminishes, either because of depletion of the source through natural erosion, or the interference of sediment supply by human-made structures, the barrier beach or spit narrows at one or more locations alongshore, and its crest exhibits greater irregularity in elevation and increased discontinuity. In some instances, sediment from the degrading part of a spit is transported alongshore to maintain growth of the distal end. Wave overwash channels are cut farther across the barrier crest or dune (Fig 9, phase 4a, Appendix). In the later stages of this phase, waves commonly transport sediment landward to build the lagoon shore. Short segments of barrier may become lowered and submerged at high tide (Fig 9, phase 4b,c).

Phase 5-Collapse or Stranding A further reduction in sediment supply and depletion of a barrier generally results in its landward migration (Fig 9, phase 5, Fig 13, Appendix). If the sea level is rising two situations may occur in the Lakes: (A) If the lagoon is shallow, wave overwash may transfer beach sediment landward and infill the lagoon allowing swash aligned barriers to migrate farther landward through a series of beach rollover cycles of alternate wave overwash and crest rebuilding (Fig 9, phase 5 ai). Continued landward migration of a barrier results in longshore stretching and given a sequence of storms can result in its submergence and stranding before it can reach the far shore (Carter et al., 1987; Taylor et al., 1999); and (B) If the lagoon is deep, a coastal barrier can become flattened, submerged and stranded along its original backshore (Fig 9, phase 5aii). A good example is Barachois spit, located in the channel east of Long Island, St. Andrew's Channel, where the distal end of the spit photographed by Tarr (1898) is now a shoal detached from its proximal end at high tide. By 2000 a new recurve ridge had developed closer to the main shore but water depth was too great to allow appreciable growth. The model for drift-aligned barriers comes from examining Sheep and Macrae Islands at the mouth of Malagawatch Harbour (Figs 6,11). The loop structures breakdown (Fig 9, phase 4b) as the island anchor and sediment source become depleted and finally become stranded following erosion of the island (Fig 9, Phase 5b). It was observed at Macrae Island and McPhee Island (Figs 6,10), that some sediment is transferred inshore from the stranded barriers to initiate the development of new spits. This recycling of sediment allows the transformation of shores from one phase to another.

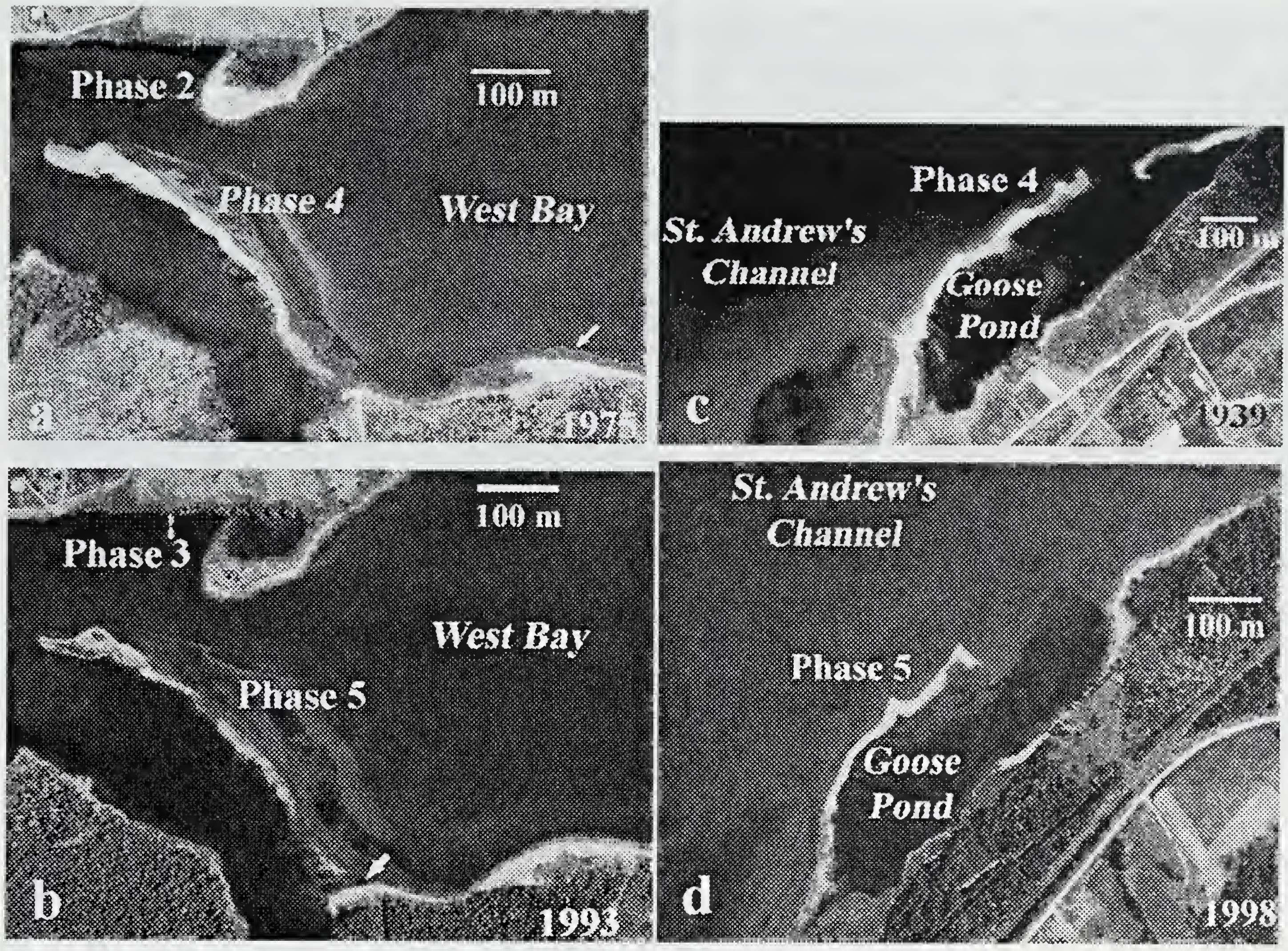


Fig 12 Two examples of barriers breaking apart, becoming submerged and migrating shoreward. At West Settlement, West Bay the entire length of the spit was lowered, overwashed by waves, and segmented between (a) 1975 (photo 75204-101) when the sediment source was depleted (arrow) and (b) 1993 (photo 93303-29) when longshore sediment transport was resumed from the east and a new spit developed across the foundation of the older one (arrow). At Goose Pond, St. Andrew's Channel, between (c) 1939 (photo A6651-60) and (d) 1998 (photo 98321-182), the northern portion of the barrier formed a separate smaller barrier against the main shoreline and the southern portion of the original barrier became shorter, more narrow and a new recurve ridge developed as part of the natural breakdown phase.

There are several examples including Goose Pond, St. Andrew's Channel, where the proximal ends of barriers have migrated landward to form new cuspate barriers (Fig 2b, location 73; Fig 9, phase 5c;) even though the central part of the barrier has been submerged and stranded. These new barriers, because they are smaller and have reconnected to the main shore, are more stable and considered to have evolved into phase 3 (Fig 12d). Once barriers have become stranded new spit growth often is observed at the proximal end of the old barriers such as West Bay Settlement, West Bay (Fig 2b, location 29, Fig 12b), signifying the resumption of sediment supply and re-initiation of phase 1.

Phase 6 -Artificially Constrained An alternative outcome of barrier change results when barriers no longer exhibit their natural character because they have been altered or constrained by human activities (Fig 13). In the past many barriers particularly along the south shore of St. Andrew's Channel became the foundation for railways and roads.

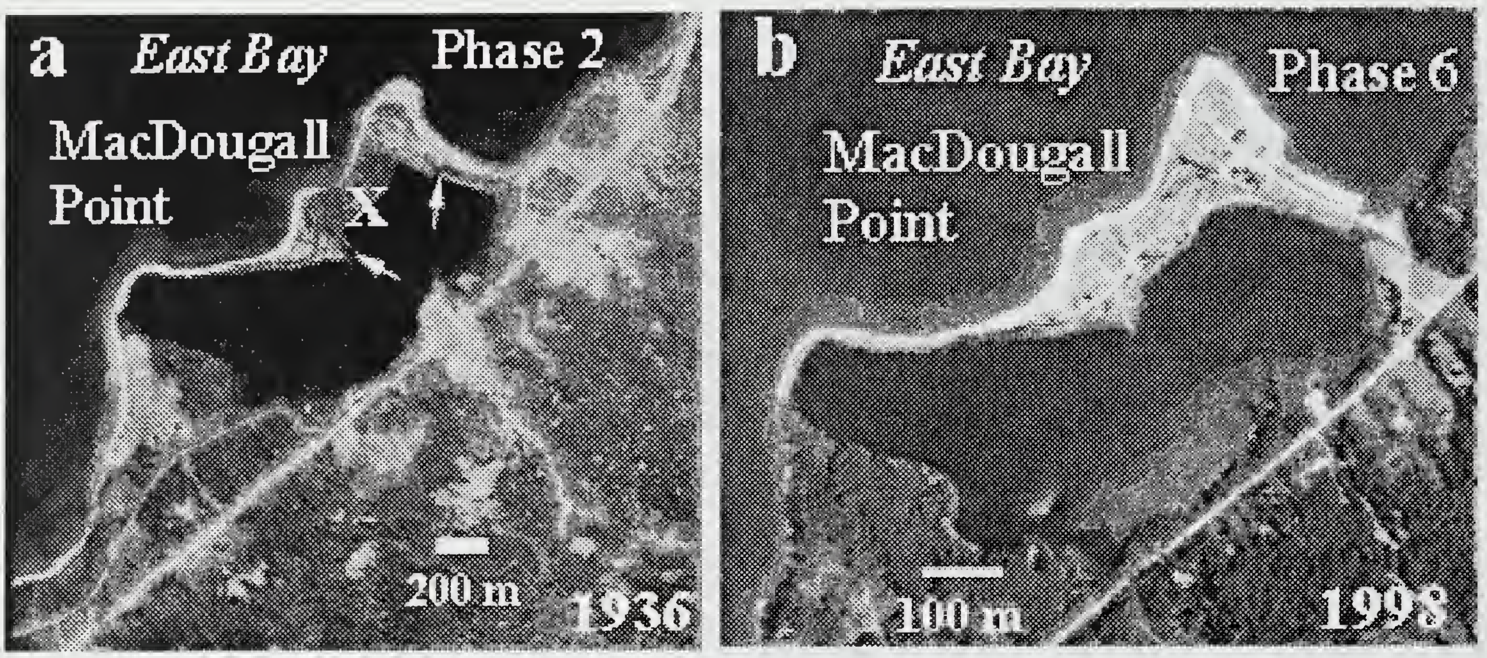


Fig 13 Two views of MacDougall Point, East Bay (a) in its natural state in 1936 when barriers had linked the central island (X) to the main shoreline forming a tombolo (air photo A5450-91) and in (b) 1998 (air photo 98322-3) when the coastal barrier was constrained in its natural evolution by groynes and other shore structures. It now forms the Ben Eoin campground and trailer park, a popular summer retreat. By 1998 only one of two natural outlets observed in 1936 (arrows) has been maintained.

Fill was required to build the railway bed across low coastal areas and boulders and quarry rock were added to protect the artificial shore structures from wave erosion (Fig 9, phase 6 a). The apparent stability of phase 2 and 3 barriers makes them attractive sites for this type of construction and subsequent alteration to phase 6. When natural shoreline erosion is halted it reduces the volume of sediment supplied to adjacent shores and can, in some cases, accelerate their erosion.

Residential developments or recreational activities on large barriers can result in compaction and modification of the natural surface, lowering of crest elevations and change or loss of natural vegetation cover. MacDougall Point, the site of Ben Eoin campground, is an example of a barrier in phase 6 (Fig 2b, locations 11,13). The development of the campground has required significant maintenance to protect the investment, including stabilizing the inlet, modifying the natural beach ridges and the building of many small groynes (a narrow structure constructed of timber, rock or concrete roughly perpendicular to shore with the intent to trap sediment transported alongshore and maintain or increase beach width).

Human activities are expanding along the Bras d'Or Lakes. In East Bay alone, 63 groynes, 44 seawalls and 19 rip rap structures were observed along the shores during the 1996 aerial video survey (Taylor and Frobel, 1998). There are also increased demands by local residents to reopen or modify the tidal inlets through small barriers to improve lagoon circulation and reduce odor; to allow the passage of fish or pleasure craft; and to reduce flooding inland (McSween, 2000). Artificial structures decrease the ability of natural shores to re-organise and recycle their sediment to form new beaches as sea level rises. Human actions introduce new phases of stability at irregular intervals which tends to disrupt and/or accelerate natural processes. The impacts of such actions have received little attention and are poorly documented. It is known that coastal barriers will breakdown naturally. How much human activities will accelerate the processes is unknown.

Present Status of Coastal Barriers on the Bras d'Or Lakes

Criteria were developed for identifying specific phases of coastal barrier evolution (Table III) and applied to 80 coastal barriers of 250 m in length within the Bras d'Or Lakes. Their physical characteristics and phase of development were assessed using the 1996 aerial video and they are listed in the Appendix. Further ground investigations should be completed to confirm the details but these results provide a useful guide concerning the present status of the coastal barriers. Although they exist, no barriers in phase 1 and only a few in phase 2 are listed in the appendix because of the restriction in the size of barriers examined. Overall 39% were in the building or established phases 2 and 3; 43.9% were in breakdown and collapse phases 4 and 5; 13.4 % were in transition between phase 3 and 4, and 3.7% were significantly constrained by human activities. Barriers identified in transition between phase 3 and 4 exhibited minor erosional and breakdown characteristics which may only be temporary and the result of recent storms. Many of these barriers may recover and remain in phase 3 depending on their ability to recycle and reorganise sediment. Coastal barriers in phase 4 and 5 are most sensitive to human activities. Care should be taken when approving land use and building permits, on and adjacent to these coastal barriers to avoid accelerating the natural breakdown process and loss of human-built coastal infrastructure.

Future Research and Summary

A conceptual model of barrier beach evolution was developed for the Bras d'Or lakes. Five phases of natural evolution were defined: (1) initiation, (2) growth, (3) establishment, (4) breakdown and (5) collapse or stranding. The resumption of the cycle and initiation of a new, often much smaller barrier can occur following phase 4 or 5. An alternative outcome (6) occurs when a natural barrier becomes constrained and/or modified by humans to the extent that natural processes are altered significantly, and it is unable to evolve naturally. The model serves as a guide for an initial evaluation of the stability of barriers and provides information to users so that the negative impacts of human activities can be reduced. Nearly 44 % of the large coastal barriers listed were identified in the breakdown phase which means they are more sensitive to human interference. Hence, a greater awareness of the natural evolutionary process is required if we are to avoid accelerating natural breakdown of shores and minimize the loss of coastal infrastructure.

The magnitude of processes such as the impacts of sea ice on coastal stability and sediment transport by waves both warrant further investigation to better understand rates of coastal change relative to the more wave exposed Atlantic coast. Much of the information presented in this paper is based on visual observations with only a few quantitative measurements. Air photos have provided information about historical changes on land but only detailed mapping of the sea floor, using new technology such as multibeam bathymetric surveys, can provide similar information offshore. Recent multibeam surveys completed by the Canadian Hydrographic Service (Paul, 2000) suggest a number of potential drowned shores which could be surveyed and sampled to document coastal evolution during the past few thousand years. From the 1996 aerial video survey a number of barriers were identified as having already gone through several phases of evolution. They would be primary sites for further surveying and sampling of older beach ridges and coring of lagoon bottom sediment to obtain material for dating the age of the barriers and analyzing when and if the lagoons switched from freshwater to saline conditions. Information about the age of the coastal barriers would provide a better understanding of the duration of specific cycles of barrier evolution and contribute to a better history of sea level change in the Lakes and a reconstruction of the paleoshorelines (Shaw et al., 2002).

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Appendix

List of Coastal Barriers (250 m or longer), in the Bras d' Or Lakes, N.S. Information was primarily derived from the 1996 aerial video survey (Taylor and Frobel,1998). The coastal barrier locations are plotted using their site number on Fig 2b.

Site No.	**Geographic Name**	**Shore Morphology**	**Seaward Connection Type**	**Seaward Connection Location**	**Physical Description (from aerial video)**	**Present Phase of Development**
	LEGEND	refer to Figures 3, 6 to 8, & 10 to 12 and Table I	Type P permanent E ephemeral A artificial	Location position along barrier		refer to Figure 9 and Table III
1	Castle Bay	Barrier Beach	P	centre	single crest, joined both ends, stable to west narrower some wave overwash to east, dune grass covered	3
2	Amagaudees Pond	Barrier Beach	A	north	multiple beach ridges north central end, joined both ends	3
3	Dhu Point	Spit	N/A	N/A	single crest and some overwash to south, multiple beach ridges to south; sediment transport in pulses alongshore distal end submerged, severely segmented,	4
4	Indian Islands West	Barrier Beach	none	none	narrow, winding, single crest, joined both ends; narrows to southeast centre migrated landward onto island, dune, some wave overwash	3 to 4
5	Indian Islands East	Tombolo	none	none	multiple ridges, dune, gradational vegetation grass to trees new spit growth north of small island	3
6	Cossett Point W	Barrier Beach	none	none	joined both ends and central anchor, single ridge to south; multiple ridges to north, grass to wooded	3
7	Cossett Point	Spit	N/A	N/A	single crest at proximal end, narrow dune; wave overwash multiple ridges at distal end, some local growth but nearly detached	4
8	Head East Bay N	Spit highway	A	north	13 groynes added, sediment trapped by 4 western ones submerged beach ridges in lagoon	6
9	Head East Bay S	Spit	N/A	N/A	multiple recurved beach ridges, grass to wooded eroding at proximal south end; building to north	3

Site No.	Geographic Name	Shore Morphology	Seaward Connection		Physical Description (from aerial video)	Present Phase of Development
			Type	Location		
10	no name	Barrier Beach	E E	north closed south open	narrow, eroded shore, multiple ridges, wooded to north, grass central area; overwash at both inlets, erosional cliffs at both ends	early 4
11	MacDougall Point	Tombolo	A	north	single crest to south, dune is continuous and grass covered; relic outlet south of island; many small groynes alongshore; campground	6
12	Marble Point	Barrier Beach	P	north	single crest, low, narrow; dune overwashed & broken, grass covered; spit at north end has prograded, more dune to south	4 to 5
13	Porphyry Point	Barrier Beach	none	none	backbarrier wetland /shallow pond; stream outlet to south of barrier; local wave overwash; wharf toward north end	4
14	Big Pond	Barrier -relict	P	submerged	totally submerged with deeper water farther landward	5
15	Lochmore Harbour	Spit	N/A	N/A	mutiple recurved ridges at distal end; grass, sharp bend in planform; washover at central area, broken grass cover, building at northeast and south ends	4
16	Lochan Fad	Barrier Beach	P	centre	narrow; segmented, submerged in centre, wave overwashed to north; Multiple ridges at ends, sparse grass cover; more dune to south	5
17	Irish Vale	Barrier -relict	P	centre	segmented, centre submerged, rest is wave overwashed south end stranded against main shore, multiple ridges,	5
18	Barachois Harbour	Barrier Beach	P P	north south	segmented, several parts submerged, central anchor eroded island spit growth north and south from island; north segment is overwashed	5
19	Evans Island North	Barrier Beach	P	centre	multiple ridges to east, grass to wooded backshore west segment more overwashed, not vegetated	3
20	Evans Island South	Spit	N/A	N/A	proximal end overwashed , partially vegetated by grass distal end is long narrow submerged ridge	5
21	Indian Island	Spit	N/A	N/A	long narrow ridge with sharp bends, partially grass covered small island anchor to south	4 to 5
22	Cape George Harbour	Spit	N/A	N/A	long, narrow, segmented at distal end; wave overwashed wider, mainly grass and scattered trees at proximal end	3 to 4

Site No.	Geographic Name	Shore Morphology	Seaward Connection Type	Seaward Connection Location	Physical Description (from aerial video)	Present Phase of Development
23	Cape George	Tombolo-paired				
a		Barrier Beach	none	none	long, narrow, joined to shores at both ends, wave overwashed south end migrated against main shore	4 to 5
b		Barrier Beach	none	none	wide, sharp bend at south end, multiple ridges, gradational vegetation grass to trees; joined both ends to shores; backshore road and campground	3
24		Barrier- relict	P	submerged	segmented, submerged narrow ridge to north and south, ridge at centre; new spit growth at north end, migrated against main shore	5
25	MacMullens Pond	Barrier Beach	P	centre	long, narrow, single crest, no backshore vegetation (video taken from too far away to obtain details)	3
26	Urquart Pond	Barrier Beach	E	centre closed	narrow, single ridge, dune broken by wave overwash wave overwash fans in lagoon have been revegetated	4
27	McLeod Point	Tombolo-paired				
a		Barrier Beach	none	none	wide, wave overwashed, little vegetation	4
b		Barrier Beach	P	centre	wooded anchor point mid way along barrier, grass covered barrier west of inlet, prograding distal end; overwashed proximal end	4
28	Dunphy Head	Spit	P	south & northwest	wooded anchor at mid spit, segmented at distal end submerged ridges, dune vegetation on proximal end	4 to 5
29	West Bay	Spit	N/A	N/A	low, long, segmented and partly submerged; nearshore shoal	5
	Settlement	Barrier-cuspate	none	none	anchored both ends, multiple ridges; grass to wooded	3
30	MacDonalds Cove	Spit	N/A	N/A	long, new growth NE at distal end past older recurves poorly vegetated , grass covered along proximal end	2
31	MacKenzies Cove	Tombolo	none	none	continuous single ridge bifurcates at one end, encloses a pond grass to wooded ; north end migrated landward into pond from east	3 to 4
32	Brians Pond	Barrier-Beach	none	none	long, narrow single ridge; anchored both ends, grass to wooded; some washover (poor video taken from too far away)	3 to 4
33	Pellier Island South	Spit	N/A	N/A	wide, broken grass cover, wave overwash and barrier thinner at proximal end, distal beach ridges recurve back toward spit	3 to 4

Site No.	Geographic Name	Shore Morphology	Seaward Connection		Physical Description (from aerial video)	Present Phase of Development
			Type	Location		
34	Sheep Island	Barrier -Looped	none	none	anchored both ends by island, multiple beach ridges to south grass to wooded	3
35	Militia Point West 1	Barrier Beach	P	northwest	joined both ends, multiple ridges to northwest, grass to wooded inlet has shifted slightly alongshore in 60 years	3 to 4
36	Militia Point West 2	Barrier Beach	E	north	Multiple beach ridges at centre, grass to wooded joined both ends	3
37	Malagawatch Harbour	Barrier Beach	E	east closed	long , narrow, multiple ridges,grass to wooded toward centre wharf by opening, some sediment accumulation	3
38	Johnson Cove 1	Barrier Beach	none	none	long, wide, multiple beach ridge, grass to wooded, smooth plan form submerged ridges in backbarrier pond; oldest ridges to west	3
39	Johnson Cove 2	Barrier Beach	none	none	long narrow, poorly vegetated; joined at both ends, small wave washover fans on backshore	3 to 4
40	Fiddle Head (Big Harbour)	Tombolo-paired	none	none	old wave washover fans proximal end; multiple ridges at north end; relic submerged spit at inner north end; small island anchor is eroding	3 to 4
41	Boom Island (Malagawatch)	Barrier Beach	none	none	continuous, old multiple recurve ridges to north, covered by wetland vegetation, single narrow ridge to south, wave overwashed	4
42	Campbell Island	Tombolo-paired				
		north	none	none	wide, mutiple ridges, grass covered to wooded;	3
		south	E	west	low vegetated dune, building from southeast to north on north barrier	
43	Red Point McKinnon Harbour	Barrier Beach	A	west	narrow, continuous, built from east to west against island anchor, partially vegetated backshore, some wave overwash, new inlet constrained by boulder riprap	4
44	Bens Beach	Barrier Beach	E	east closed	wide, continuous, with multiple ridges, grass to wooded; lower more washover to east, inlet shifted east between 1939 and 1998	3
45	Gillis Beach	Barrier Beach	A E	centre west	joined both ends multiple ridges to northeast, grass to wooded narrow overwashed low ridge to southwest, irregular sand bar offshore; low submerged backbarrier beach ridges	4

Site No.	Geographic Name	Shore Morphology	Seaward Connection Type	Seaward Connection Location	Physical Description (from aerial video)	Present Phase of Development
46	Jamesville East	Barrier Beach	A	centre closed	appears railway line built on barrier beach foundation, sediment accumulating along seaward side of railroad	6
47	Plaster Cove	Barrier Beach	none	none	continuous, joined at ends & gypsum outcrops; multiple beach ridges; grass to wooded in south; single overwashed ridge to north	3 to 4
48	Grass Cove MacRitchies Pond	Barrier Beach	E	south	wide continuous, joined both ends, multiple beach ridges; grass to wooded; hwy and wetland along backshore,	3
49	Muskell Harbour	Spit	N/A	N/A	bulbous distal end with multiple recurve ridges, wooded proximal end more narrow, dune grass	3
50	Burnt Point	Barrier Beach	none	none	wide, attached both ends, very little vegetation road on backshore, new road cuts after 1995	3
51	Neil Island	Tombolo	none	none	narrow in central part, Y junction at island end; submerged ridges to west and shoal to north and west; also connected to small adjacent island	4
52	Washabuck Centre	Tombolo-paired				
		northeast	P	east	wide multiple ridges to south of inlet, barrier building at inlet	3 to 4
		southwest	none	none	wide, multiple ridges, gradational grass to wooded cover	3
53	Hazeldale	Barrier Beach	E	east closed	single narrow ridge, dune vegetation, building from west to east, sand accumulated east of barrier; shallow lagoon,	3
54	The Harbour Baddeck Bay	Spit	N/A	N/A	narrow single ridge, anchored to island , wooded barrier and pond to south; building small recurves north of island ; wave washover and barrier narrowing south of island	4
55	Poker Dans Pond	Barrier Beach	none	none	single dune ridge continuous, anchored to gypsum outcrops, grass only, dune scarped, minor overwash to east; more stable to west,	early 4
56	MacKillop Pond	Barrier Beach	P	centre	east barrier encloses wetland, more stable, multiple ridges at northeast end, dune grass; west portion degraded and recurve ridges at inlet;	3 to 4
57	MacDonald Point Starks Pond	Barrier-cuspate	none	none	multiple recurved ridges at mid point; spit built from east to west; more sand to east, west barrier single ridge,	3
58	Black Island	Tombolo-paired	P	east & west	mid point island anchor and cliff anchor to south;	
a	Fraser Point	shoal			submerged relict ridges	5
b		Barrier Beach	none	none	wide, multiple ridges to south, dune grass to wooded	3

Site No.	Geographic Name	Shore Morphology	Seaward Connection Type	Seaward Connection Location	Physical Description (from aerial video)	Present Phase of Development
59	Coffin Point	Barrier Beach	none	none	single ridge, connected both ends, northwest point is eroding;	3
60	Point Clear (Robenas Pond)	Barrier-cuspate	E	west	dune with multiple ridges grass to wooded to northeast low, wave overwashed single ridge to west	3 to 4
61	McGreadyville	Spit	N/A	N/A	wide continuous, multiple dune ridge , grass cover only, no trees building to southwest	2
62	Barachois	Barrier Beach	P	northeast	dune with multiple ridges to northeast and west ends; low narrow overwashed single ridge at northwest corner	4
63	McLean Point	Barrier-relict	P	centre	segmented and partly drowned, shoal in centre; dune to north and south with sparse grass; north and south ends wave overwashed;	5
64	Ironville	Barrier-cuspate	none	none	symmetrical barriers, grass covered minor dune; appears building at northwest end of point	3
65	Neil Beach	Barrier-cuspate	P	north	segmented , wave overwashed to south, shoal at north end short segment of multiple dune ridges	5
66	Dougall Point	Barrier-cuspate	E	north	narrow ridge along north shore, multiple ridges at distal end, grass,	3
67	Beaver Cove	Barrier -cuspate	none	none	continuous, variable width; wide to north, narrow to south, gradational vegetation- grass to wooded; dune scarped to west and south; relict vegetated flood delta or beach ridges in pond	3
68	McLean Beach Point	Barrier-cuspate				
a			P	south	low, single dune ridge to south, some wave overwash	4
b			none	none	multiple dune ridges to north	3
69	Shunacadie	Tombolo-paired				
a		east	P	east	east segmented, submerged, wooded small islands remain;	5
b		west	E	west open	single dune ridge along west shore, broken by wave overwash to lagoon; large wharf to east in 1939, now gone;	4
70	Big Pond Shunacadie	Barrier Beach	P	northeast	segmented, narrow ridge on both sides of central multiple beach ridges centre- grass to trees; stable to north; single dune ridge on west shore	4
71	Long Beach Point	Barrier-cuspate	none	none	wide with multiple dune ridges, grass to wooded vegetation cover more sand onshore & offshore than other nearby sites	3
72	Goose Pond	Barrier-relict	P	north	segmented submerged northern end; new barrier stranded	5

Site No.	Geographic Name	Shore Morphology	Seaward Connection		Physical Description (from aerial video)	Present Phase of Development
			Type	Location		
					onshore since 1930s; single dune ridge to south, overwashed	
73	Christmas Island	Tombolo-relict				
a			E	south	wide multiple beach ridges to north and south; grass to wooded	3
b				open	narrow single ridge along outer shore btwn islands, wave overwashed	4
74	Grand Narrows	Barrier Beach	E	north	low narrow overwashed ridge to east and centre; multiple beach ridges truncated & submerged offshore at central point	late 4
75	Pipers Cove	Barrier Beach	E	west closed	smooth continuous dune single ridge, grass covered, no overwash	3
76	Benacadie west	Barrier Beach	E	west closed	smooth continuous dune single ridge; grass covered, no overwash wider toward west end	3

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of the

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HALIFAX, NOVA SCOTIA

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GENERAL INTRODUCTION: CONSERVING NOVA SCOTIA'S BIODIVERSITY

J.H. MARTIN WILLISON[1*] and CHRISTOPHER A. MILLER[2]

[1] *School for Resource & Environmental Studies, and Biology Department*
Dalhousie University
Halifax, Nova Scotia, B3H 3J5

[2] *Wetlands Research Centre and Department of Biology*
University of Waterloo
Waterloo, Ontario, N2L 3G1

The papers on biodiversity in this issue focus on the richness of life in Nova Scotia, and the means by which this richness might be conserved. Mammals, birds, fish, beetles, and diatoms are examples of the richness of life described in the volume. The conservation status of selected species is outlined, as are the threats to these species. Special attention is paid to moose and roseate terns, and a wide range of birds, beetles, fish, mammals and other species receive some attention. Conservation options based on the protection of habitat in Nova Scotia, as well as comprehensive landscape-scale strategies for biodiversity conservation planning, are similarly described both in detail and in general by a variety of authors.

Les articles du présent volume portent principalement sur la richesse du vivant en Nouvelle-Écosse et sur les moyens de conserver cette richesse. Mammifères, oiseaux, poissons, coléoptères et diatomées sont au nombre des taxons traités dans le volume. On décrit la situation de certaines espèces et les menaces qui pèsent sur elles. Une attention particulière est accordée à l'orignal et à la Sterne de Dougall, et une grande variété d'oiseaux, de coléoptères, de poissons, de mammifères et d'autres espèces sont également considérées. Plusieurs auteurs décrivent de manière générale ou détaillee des options en matière de conservation fondées sur la protection des habitats en Nouvelle-Écosse ainsi que des stratégies globales à l'échelle des paysages pour la planification de la conservation de la biodiversité.

Introduction

The Earth is often regarded as being composed of a number of overlapping spheres, such as: lithosphere, hydrosphere, atmosphere, and biosphere. The last of these is the "sphere of life", which is arguably the Earth's most distinctive feature. Over ten million species of multi-cellular life forms are thought to exist, and this number may be matched by the many varieties of microbial life forms (for an introduction, see Gaston & Spicer 1998). Life forms collectively constitute "biodiversity", which refers to the sum of the richness of life - including genetic diversity (molecular blueprints), organismal diversity (range of taxonomic forms), and ecosystem diversity (living communities, including their abiotic determinants). For a detailed discussion of biodiversity, see E.O. Wilson's 1992 book, The Diversity of Life. A lot of this diversity is, regrettably, threatened by the sheer number of humans inhabiting the planet.

During the most recent 200 years, the human population has increased roughly 6-fold to about 6.3 billion in 2003. Not only are humans remarkably numerous, but they are also remarkably consumptive in ecological terms (for a general introduction, see Freedman 1998). Modern humans consume not only food in large quantities, but also large quantities of materials such as fossil fuels and building materials. No other animal is, or ever has been, as consumptive in relation to its size.

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[*] Author to whom correspondence should be addressed

Humans are placing considerable stress on Earth's natural systems and processes, which is revealed in many forms of global change, including significant changes in the chemical composition of the atmosphere and the biological composition of the biosphere. These changes cannot continue indefinitely without triggering homeostatic phenomena (see Lovelock 1979). Current human-caused changes in the biosphere are generally described as "biodiversity decline", and "extinction spasm". Although there is no scientific agreement about the rate at which biodiversity is currently declining, there is agreement that it is accelerating (see for examples, Lawton & May 1995, Soulé 1991). Soulé (1991) considers that we can expect to lose 25-50% of species diversity in the current human-caused extinction spasm, the precise amount being dependent on how the next 100 years unfolds, and he provides a strategic analysis of the means by which we can apply conservation planning, and thereby keep the losses at the lower end of this range.

In response to the growing stresses on the biosphere caused by expansion of the human enterprise, global and national conservation strategies are being devised by governments and non-government organizations to protect the Earth's resources and biodiversity (for examples, see Munro & Holdgate 1991, Canadian Biodiversity Strategy 1995). A wide range of conservation strategies, protocols and methods have been developed. These vary from approaches requiring a high degree of technological control that can be applied only in special circumstances, such as with gene banks and zoos, to methods that are elementary and generally applicable, as in the protected areas and community stewardship approaches.

This issue of the Proceedings of the Nova Scotian Institute of Science addresses contemporary matters of biological conservation in Nova Scotia. A lot of conservation research is actively being undertaken within the province, representing a microcosm of the global conservation effort. This issue attempts to assemble a portion of this knowledge. It deals first with the inventory of selected aspects of biodiversity, and then moves on to species-specific conservation issues, and finally to spaces-orientated approaches.

Biodiversity of Nova Scotia

In order to plan for the conservation of biodiversity in Nova Scotia, it is useful to have access to reliable inventories of species. Detailed lists are currently available for several taxonomic groups within the province, including: plants (Roland and Smith, 1969, Roland 1998), birds (Tufts & McLaren 1986), herpetofauna (Gilhen 1984), and certain insects (Brunelle 1997, 1999). In other cases, Nova Scotian biologists may turn to lists for nearby regions (for snails and slugs of Maine, for example, see Martin 1999, 2000; for mosses of the Maritime Provinces, see Ireland 1982). As distance from our region increases, however, the general reliability of these records begins to decline. This makes it imperative to develop and maintain detailed lists of biological diversity specific to Nova Scotia.

In this issue of the Proceedings of the Nova Scotian Institute of Science, Fred Scott and Andrew Hebda provide a comprehensive annotated list of mammals occurring within the province. The authors provide information on the taxonomy, distribution, habitat, and conservation status for each of 91 species identified. Both terrestrial and marine mammals are considered. This annotated list will provide a useful framework and standard for a wide range of future ecological studies.

In the next paper, David McCorquodale and Søren Bondrup-Nielsen examine the occurrence and distribution of Cerambycid beetles within Nova Scotia. Cerambycids are a family of long-horned beetles with larvae that bore into wood. The authors report the presence of 85 species of Cerambycids in the province, based on a careful and thorough review of museum records. They contrast these findings with the 55 species that are supposed to occur within the province based on reviews of Cerambycid distributions from Canada and North America. This contrast is a powerful reminder that even respected compilations of information on biodiversity can be incomplete or misleading.

In the next paper in this issue, Alison Sherwood and Ronald Deckert report on the diatoms found on rocks in a small stream running out of Williams Lake near Halifax. The authors identify many species not previously reported from the province. In this case, a single small site provided a wealth of records of new species, showing how little we know about the relatively obscure organisms that abound in Nova Scotia.

In the following paper in the issue, Daniel Kehler and co-authors report on the relationship between habitat and beetle diversity in forest stands from central Nova Scotia. Hardwood stands are shown, in general, to possess a greater richness of beetle diversity than softwood stands, with the amount of dead wood biomass being the determining factor in this regard. While the human view of a "healthy forest" might be of one that is full of young and vigorously-growing trees, for beetles a healthy forest is full of decaying wood. Seen through the eyes of a typical beetle (if such can be imagined), the trees are most valuable once they die and begin to decay.

The status of species and habitats

Rare and endangered species in Canada are examined by a number of committees constituted under national and provincial legislation. The Committee on the Status of Endangered Wildlife in Canada is constituted under the Canada Species At Risk Act, and the Nova Scotia Species at Risk Working Group is constituted under the Nova Scotia Endangered Species Act. These committees must have adequate knowledge to address the conservation needs of species of concern. Information on population trends over several years is required, for example, to distinguish a naturally rare species from one that is undergoing a severe decline in numbers. The status of the former might be classified as being of "special concern", while the latter might be considered "threatened". Four papers in this issue examine the status of select species occurring within the province, and the habitats on which they depend.

Seabirds nest plentifully on the Bird Islands north of Cape Dauphin on Cape Breton Island. Because the Bird Islands provide such important breeding habitat, they have been somewhat protected from human incursions for many years. David McCorquodale and colleagues have pulled together data that demonstrate the population trends of the birds nesting on the islands, and show in their paper that dramatic shifts have occurred over the past 75 years. The population of kittiwakes, for example, has exploded on the islands, while murres and two species of terns have completely disappeared.

In the next paper in this issue, Marty Leonard, Andrew Boyne and Sherman Boates examine the roseate terns of Nova Scotia, with particular focus on the terns of Country Island in Guysborough County. This specific case of an endangered bird species provides some general lessons about conservation planning. The major threats to the terns come from facultative predators, notably gulls, that have become specially numerous as a result of the availability of food that can be scavenged. The authors conclude that the key to maintaining terns is to control the populations of gulls in and around colonies of breeding terns. They show that this can be achieved by non-lethal means. In general terms, this work clearly demonstrates the value of observation, experiment, and ongoing monitoring.

One approach to designing effective conservation strategies is to focus on particular species that will provide an "umbrella" for a wide range of other species. In other words, by ensuring that one far-ranging species is adequately protected, many other species with smaller ranges will benefit from the same protection. In Nova Scotia, the moose is a good example of an "umbrella species", because it is very large and therefore needs a lot of habitat. By protecting enough habitat for moose, we can ensure that an adequate amount of space is protected for a variety of other species as well. The moose found on Nova Scotia's mainland are in severe decline and were listed as endangered by Nova Scotia's Department of Natural Resources in 2003. If this decline is due to declining habitat quantity or quality it may be an ominous signal for the health of many other species within the province. In their paper "The distribution, status and habitat associations of moose in mainland Nova Scotia", Tamaini Snaith and Karen Beazley provide a thorough review of the information necessary for ascertaining both the condition of the province's moose and also what might be done to lessen the risk of extirpation.

Special conservation attention needs to be paid to aquatic species because water is especially susceptible to pollution and other insidious threats to biodiversity. In the next paper in this issue, Yoichiro Kanno and John MacMillan examine the fish community of River Philip in Nova Scotia's Cumberland County. The authors develop and test an "index of sustainable coldwater streams" that can be used as a guide for the maintenance of suitable aquatic habitat conditions in other rivers and watersheds in Nova Scotia.

Landscape-scale Conservation Planning

The last four papers in this issue deal with spaces-orientated approaches to conservation in Nova Scotia. A landscape-level approach is founded upon intimate knowledge of the natural science and biogeography of a defined region, and is arguably the most essential component of a biological conservation plan (see Hummel 1989, Noss & Cooperrider 1994, Beazley 1997). There are many suitable information sources for landscape-scale conservation planning in Nova Scotia. The layers of rock that provide the foundation of Nova Scotia are described in a beautifully illustrated book of the geology of the region (Atlantic Geoscience Society 2001) and the landscapes themselves have been dissected by Davis & Browne (1996) in the Natural History of Nova Scotia. Petrie & Raymond (2002) provide comprehensive information for the Bras d'Or Lakes region of Cape Breton. Conservation planning itself has been examined at the provincial scale in several studies (Ogilvie 1992, Lynds & Leduc 1995, Beazley 1997, Beazley et al. 2002).

In this issue, Karen Beazley and co-workers examine the potential effects of road density on wildlife, paying special attention to moose populations. The authors show that there is a strong negative correlation between the density of roads within the province and the density of moose. Areas of the province having relatively few roads, for instance, are places most likely to possess remnant pockets of moose. While the availability of suitable habitat also affects the distribution of moose, the researchers found this to be a somewhat less important variable than road density. This work clearly shows the importance of maintaining large roadless wilderness areas as a key component of the province's biodiversity conservation strategy.

In the next paper in this issue, Karen Beazley and co-authors describe the products of a workshop that was held in 1999 to develop a "biodiversity conservation vision" for Nova Scotia. The "vision" includes maps showing geographic areas in special need of protection. The results of the workshop emphasize the need for setting aside an adequate amount of land, to ensure that a full spectrum of habitat and landscape diversity occurring within the province is protected. Special emphasis is also placed upon the need for adequate connectivity between protected sites to ensure sufficient genetic exchange among dispersed meta-populations. Lastly, the report also details a vision for the protection of marine biodiversity off the coast of Nova Scotia.

Systems of terrestrial protected areas are rarely planned with the unique considerations of aquatic environments in mind, perhaps because the needs of aquatic systems are not easily addressed in this way. Kanno and Beazley examine this topic in the next paper in this issue by paying attention to specific fish species and fish habitats. The authors conclude that certain species, notably Atlantic Whitefish (*Coregonus huntsmani*) and Brook Trout (*Salvelinus fontinalis*), are suitable "focal species" and that watershed-based planning for specific rivers is deserved. The Petite Riviére and River Philip watersheds are selected, in particular, as places in need of special conservation measures, based on the findings of the focal river approach.

In the final paper on biodiversity in this issue, Christopher Miller examines the private land holdings of a forestry company, Stora Port Hawkesbury Ltd., and analyzes the capacity for the company's land holdings to contribute to the wider system of protected areas within Nova Scotia. By using a "coarse-filter" approach, Miller shows that properly selected nature reserves established on some blocks of the company's land could make a strong contribution to nature conservation in the province by filling gaps in the publicly owned network of representative protected areas.

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ANNOTATED LIST OF THE MAMMALS OF NOVA SCOTIA

FRED W. SCOTT[1*] and ANDREW J. HEBDA[2]
[1]*Research Associate, Nova Scotia Museum of Natural History,*
and Curator, Wildlife Museum, Biology Department,
Acadia University, Wolfville NS B0P 1X0
[2]*Curator of Zoology, Nova Scotia Museum of Natural History,*
1747 Summer Street, Halifax, NS B3H 3A6

The latest taxonomic, distributional, habitat and conservation status information is presented for a total of 91 species of marine and terrestrial mammals presently or historically known from Nova Scotia. Four of them are extirpated and one is extinct. Of the 86 remaining species 51 are terrestrial (46 native, 5 introduced). The terrestrial mammals include 9 species of Insectivora, 6 (+ one tentative) of Chiroptera, one Primate, 12 Carnivora, 1 Perrissodactyla, 3 Artiodactyla, 19 Rodentia and 1 Lagomorpha. Native species include Boreal, Transition Zone and Austral elements, the result of Nova Scotia's mid-latitude position on the continental coast.

The 32 recorded marine species include 6 Carnivora (5 seals, walrus) and 26 Cetacea: Delphinidae (10 species), Phocoenidae (1), Monodontidae (1), Kogiidae (2), Physeteridae (1), Ziphiidae (4), Eschrichtiidae (1, extirpated), Balaenopteridae (5) and Balaenidae (1).

Since 1971 four small mammal species (*Sorex gaspensis, S. dispar, Glaucomys volans* and *Microtus chrotorrhinus*) have been added to the provincial fauna, as a result of the first systematic and intensive sampling ever done in Nova Scotia. All are disjunct and three of them are restricted to forested talus habitats in the Cobequid Mts. or the Cape Breton Highlands. With the two disjunct species already known (*Sorex arcticus maritimensis* and *Peromyscus leucopus caudatus*), there are 6 disjunct mammals in the province, comprising 14.3 % of native non-volant terrestrial mammals, 33 % of insectivores and 18.8 % of native rodents. Two of them (*Sorex gaspensis* and *Microtus chrotorrhinus*) occur only on Cape Breton Island. No other area of similar size north of Mexico has a comparable proportion of disjunct mammals.

Cape Breton Island historically has had a depauperate mammal fauna, lacking 8 species that were present on the adjacent mainland. The building of the connecting Canso Causeway in 1953-55 had a major zoogeographic impact, as it caused the western third of the strait to freeze over in winter and allowed the invasion and establishment of four large mammal species (*Canis latrans, Procyon lotor, Mephitis mephitis* and *Lynx rufus*).

Le document présente l'information la plus récente sur la taxonomie, la répartition, l'habitat et la situation de 91 espèces de mammifères marins et terrestres qui vivent actuellement ou ont déjà vécu en Nouvelle-Écosse. Quatre d'entre elles ont disparu et une est éteinte. Sur les 86 autres espèces, 51 sont terrestres (46 espèces indigènes et 5 espèces introduites). Les mammifères terrestres comprennent 9 Insectivora, 6 (+ une espèce provisoire) Chiroptera, un Primate, 12 Carnivora, un Perrissodactyla, 3 Artiodactyla, 19 Rodentia et un Lagomorpha. La Nouvelle-Écosse étant située à une latitude moyenne sur la côte continentale, les espèces indigènes qui y vivent sont des éléments de la zone boréale, de la zone de transition et de la zone australe.

Parmi les 32 espèces marines signalées, on compte 6 Carnivora important a (5 phoques et le morse) et 26 Cetacea: Delphinidae (10 espèces), Phocoenidae (1), Monodontidae (1), Kogiidae (2), Physeteridae (1), Ziphiidae (4), Eschrichtiidae (1, disparue), Balaenopteridae (5) et Balaenidae (1).

Depuis 1971, à la suite du premier échantillonnage systématique et intensif mené en Nouvelle-Écosse, quatre espèces de petits mammifères (*Sorex gaspensis, S. dispar, Glaucomys volans* et *Microtus chrotorrhinus*) se sont ajoutées aux espèces fauniques de la province. Ce sont toutes des espèces disjointes, et trois d'entre elles sont confinées aux talus d'éboulis boisés des monts Cobequid ou des hautes-terres du Cap-Breton. Si on inclut les deux espèces disjointes déjà connues (*Sorex arcticus maritimensis* et *Peromyscus leucopus caudatus*), il existe 6 espèces disjointes de mammifères dans la province, qui représentent 14,3 % des mammifères terrestres indigènes qui ne volent pas, 33 % des Insectivores et 18,8 % des Rongeurs indigènes. Deux d'entre elles (*Sorex gaspensis* et *Microtus chrotorrhinus*) ne sont présentes que dans l'île du Cap-Breton. Au nord du Mexique, aucune autre région de taille semblable n'a une telle proportion d'espèces disjointes de mammifères.

Dans le passé, l'île du Cap-Breton renfermait relativement peu de mammifères : on y trouvait 8 espèces de moins que dans la partie continentale de la Nouvelle-Écosse. La construction de la levée de Canso en 1953-1955 a eu un impact important zoogéographique du fait que, depuis, le tiers ouest du détroit gèle durant l'hiver, ce qui a permis à quatre espèces de gros mammifères (*Canis latrans, Procyon lotor, Mephitis mephitis* et *Lynx rufus*) de gagner l'île et de s'y établir.

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[*] Author to whom correspondence should be addressed.

Introduction

A first step in any conservation effort is an assessment of what is already known, particularly on the fundamental questions of what species live in an area, where and when they occur, and how abundant they are. Comprehensive and current annotated taxonomic checklists provide a temporal and spatial overview of the biodiversity of a group in a region or jurisdiction, and an entry point to the important literature.

This list was first compiled by FWS in 1993 while Assistant Curator of Zoology at the Nova Scotia Museum of Natural History, and revised as necessary. Since moving to Acadia University in 1995, he and AJH have jointly continued to update the list and make it available to all interested parties. The decision to publish it was prompted largely by the fact that it has been 62 years since the appearance of the last provincial list (Smith 1940), which was limited to land mammals. The taxonomy used by Smith is seriously out of date and there have been major additions of species, range extensions and changes in status since then.

Future revisions and updates of this list will be posted on the Nova Scotia Museum of Natural History website at *http://museum.gov.ns.ca/mnh/index.htm.*

Taxonomy

The higher taxonomy adopted is that of Wilson & Reeder (1993), with the exception of the placement of the cougar in the subfamily Acinonychinae, in accordance with molecular genetic work by Janczewski et al. (1995). Wilson and Reeder also list taxa from family level down in strictly alphabetical order and this conveys nothing about supposed relatedness, so at those levels we have retained the traditional sequences of families, genera and species. Wilson and Reeder's species definitions have also been adopted, except for our retention of *Myotis septentrionalis* as separate from *M. keeni* (van Zyll de Jong 1985). Subspecies are not explicitly considered in this list unless they constitute disjunct Nova Scotian populations. Common names are generally those used in Banfield (1974), with modifications based on more recent usage, and alternate or formerly accepted names in parentheses. Colloquial names widely used in Nova Scotia are in quotation marks.

Information sources

The standard references for distribution and biology are Peterson (1966) and Banfield (1974); only overlooked old information, corrections to published literature, significant new information, or occurrences of rare or new taxa, are separately referenced in this list.

For most mammals, especially the small non-marine species, the status, distribution and habitat preferences are based on the largely unpublished collection records of the Nova Scotia Museum of Natural History and the Wildlife Museum at Acadia University, mostly from 1971 onwards. Also included are all records from the Canadian Wildlife Service surveys of the mammals of Kejimkujik and Cape Breton Highlands National Parks in 1971 and 1974, as well as about 1500 records of small mammals from Nova Scotia in collections of other North American museums. All of these records are attributed here as the Nova Scotia Mammal Collection Record Database (NS MCRD). Most of them (5278 of approximately 7081) are accessible online at the Nova Scotia Museum of Natural History; all are accessible through FWS at the Wildlife Museum, Acadia University. Specimens in the collection of the Nova Scotia Museum of Natural History are referenced as (NS MNHC); non-collection information in that museum's files is referenced as (NS MNH).

For managed terrestrial game and furbearing species, and for some others, the latest status information is from the Nova Scotia Department of Natural Resources Wildlife Division, Kentville NS, and referenced as (NS DNR).

Until recently the great majority of precisely located cetacean records were strandings of dead animals, which do not necessarily reflect living distribution or abundance. We chose to cite significant stranding occurrences because they are often historically important and because many of those animals also ended up in permanent museum collections and in the published literature. Strandings are listed first in the species accounts. Nova Scotia stranding records from 1949 to 1970 are summarized in Sergeant et al. (1970); the most recent summary of strandings for Sable Island covers the period from 1970 to 1998 (Lucas & Hooker 2000). Stranding records not cited from these or other publications are from the Nova Scotia Marine Animal Stranding Report Database (MASRD), now held at the Nova Scotia Museum of Natural History, Halifax. In addition to summarizing the current knowledge of the status of wild populations, we have also made a point of citing all notable reliably identified published or unpublished sight records of live animals, since they more accurately represent the distribution and habitat preferences of wild populations.

Conservation status

Formal conservation status is indicated when it has been assigned. On the national level status is assigned by COSEWIC (Committee on the Status of Endangered Wildlife in Canada). In Nova Scotia, an *ad hoc* Species at Risk Working Group was established in late 1996 by the Wildlife Division of the Nova Scotia Department of Natural Resources to provisionally evaluate and rank Nova Scotian biota, pending the enactment of formal legislation. FWS was a member of that *ad hoc* committee's Mammal Working Group. Rankings were based on the then-current IUCN criteria and were summarized by colour code: Red (known or believed to be at risk of extinction or extirpation); Yellow (known or believed to be particularly sensitive to human activities or natural events); Green (known or believed to be not at risk from human activities or natural events). All native non-marine mammals have been provisionally ranked.

With the passage of the Nova Scotia Endangered Species Act (1998) (NSESA) a formal Species At Risk Working Group (SARWG) was established which is evaluating and ranking all species, with the priority on those with existing COSEWIC status, and those provisionally ranked Red by the *ad hoc* Working Group. FWS is also a member of SARWG.

Annotated list

ORDER INSECTIVORA (SHREWS, MOLES, TENRECS, HEDGEHOGS)
Family Soricidae (Shrews)

1. *Sorex arcticus* Kerr 1792, subspecies *maritimensis* Smith 1939. Arctic Shrew (Saddle-backed Shrew, Black-backed Shrew). Green (NS). *Disjunct.* Population in NS/southeast New Brunswick (ssp. *maritimensis*) is widely separated from main population north of the St. Lawrence River and van Zyll de Jong (1983) suggested it was a good species; chromosomal (Volobouev & van Zyll de Jong 1988) and new DNA analysis (Fumagalli et al. 1999, Stewart et al. 2002) support recognizing this population as specifically distinct (*Sorex maritimensis* Smith). Mainland only. Locally common in floodplain wet meadows and marsh margins, especially dyked coastal marshland in Kings and Cumberland Counties (NS MCRD). Its

apparent inability to colonize adjacent habitats makes it especially vulnerable to increased winter/spring flooding caused by climate warming (Herman & Scott 1992).

2. *Sorex cinereus* Kerr 1792. Common Shrew (Masked Shrew, Cinerous Shrew). Green (NS). Common throughout, including many coastal islands, and found in all but permanent wetlands and urban habitats. Probably the most abundant of all NS mammals; populations fluctuate irregularly (NS MCRD). The only native small mammal on Seal Island, 24 km from the mainland. Populations on Seal and Bon Portage Islands show some genetic differences from mainland populations (Stewart & Baker 1992).
3. *Sorex fumeus* Miller 1895. Smoky Shrew. Green (NS). Mainland only; Cameron's (1958) single Cape Breton Island record was a misidentified old *S. cinereus* (NS MCRD). Common in deciduous and mixed forests, especially along streams; uncommon to occasional in other forest or tall shrub habitats (NS MCRD).
4. *Sorex gaspensis* Anthony & Goodwin 1924. Gaspé Shrew. Special Concern (COSEWIC 1988). Yellow (NS) *Disjunct.* First collected in 1971 on Kellys Mtn, but initially misidentified (Scott & van Zyll de Jong 1989); discovered in 1974 in Cape Breton Highlands National Park (Roscoe & Majka 1976). Rare and very local on forested talus around periphery of Cape Breton Highlands (Scott 1988). Differs morphometrically from *S. dispar* only in size, not in shape, and the two may be conspecific (Scott & van Zyll de Jong 1989). DNA comparison of the two is under way by FWS and Don Stewart of Acadia University.
5. *Sorex dispar* Batchelder 1911. Long-tailed Shrew (Rock Shrew). Yellow (NS). *Disjunct.* Discovered in 1984 (Scott 1987). Rare and very local on forested talus in the Wentworth Valley (Scott & van Zyll de Jong 1989) and Portapique River Valley (Woolaver et al. 1999) of the Cobequid Mountains.
6. *Sorex palustris* Richardson 1828. Water Shrew. Green (NS). Uncommon and local throughout along streams, lake shores and sometimes rocky coasts (NS MCRD).
7. *Sorex hoyi* Baird 1857. Pygmy Shrew. Green (NS). Uncommon and very local throughout, in floodplain marsh margins, oldfields, regenerating clearcuts and mature forests, including those on talus slopes (NS MCRD).
8. *Blarina brevicauda* (Say 1823). Short-tailed Shrew ("mole"). Green (NS). Common throughout in all but permanent wetlands and urban habitats; populations fluctuate irregularly (NS MCRD).

Family Talpidae (Moles)

9. *Condylura cristata* (Linnaeus 1758). Star-nosed Mole. Green (NS). Locally common throughout where soils are suitable, especially near permanent water (NS MCRD).

ORDER CHIROPTERA (BATS)

Family Vespertilionidae (Plain-nosed Bats)

10. *Myotis lucifugus* (Le Conte 1831). Little Brown Bat. Yellow (NS). Occurs throughout; most abundant and widespread of our bats. Forms maternity colonies in buildings, sometimes with thousands of bats. Hibernates in caves and mines. Only one large hibernaculum known, at Hayes Cave, Hants Co. (6000-9000 bats) (Scott 1985). Second largest known is in an abandoned mine at Lake Charlotte (~3000 bats; NS DNR). About 11 smaller hibernacula (25-1000 bats) known, in caves or abandoned mines (Taylor 1997). Total known wintering population is about 15,000, out of an estimated Nova Scotia population of ~ 300,000 (Scott 1995).

11. *Myotis septentrionalis* (Trouessart 1897). Northern Long-eared Bat. YELLOW (NS). Uncommon throughout, apparently seldom in buildings. Hibernates in small numbers in caves and mines, at most if not all of the sites used by *lucifugus*, and possibly some by itself (NS MCRD).
12. *Pipistrellus subflavus* (F. Cuvier 1832). Eastern Pipistrelle. YELLOW (NS). Rare, western and central mainland only; apparently never in buildings here. Hibernates in caves and mines. Only 2 non hibernating records (NS MCRD); present in small numbers in Hayes Cave from late 1950s to 1963 but not seen there since (Scott 1985).
13. *Lasionycteris noctivagans* (Le Conte 1831). Silver-haired Bat. YELLOW (NS). One summer record, Kejimkujik National Park (NS MCRD). Probably migratory.
14. *Lasiurus borealis* (Müller 1776). Red Bat. YELLOW (NS). Rare, probably widespread. Migrates. 3 specimen records (NS MCRD). The first confimation of breeding came in August 2001 when a female and four young were discovered by Bob and Tracy LeBlanc in a horse-chestnut tree at Sand Beach near Yarmouth and observed/ photographed over several days before they left (Lavers 2002); copies of the photos are on file at NS MNH and DNR.
15. *Lasiurus cinereus* (Palisot de Beauvois 1796). Hoary Bat. YELLOW (NS). Uncommon, probably widespread. Migrates. 9 specimen records, 3 sight records (NS MCRD) plus 4 new sight records at Bon Portage Island, Shelburne Co., in 1998-99 (Scott 1999).

?. *Eptesicus fuscus* (Palisot de Beauvois 1796). Big Brown Bat. Hibernates preferentially in buildings but also in caves and mines. Has been very tentatively identified at Hayes Cave (NS MNH) but not yet confirmed.

ORDER PRIMATES (LEMURS, MONKEYS, APES, HUMANS)
Family Hominidae (Great Apes, Humans)

16. *Homo sapiens* Linnaeus 1758. Humans, People. Native and invaded/introduced. Common throughout.

ORDER CARNIVORA (CARNIVORES)
Family Canidae (Wolves, Dogs, Jackals, Foxes)

17. *Canis lupus* Linnaeus 1758. Grey Wolf (Timber Wolf). EXTIRPATED (NS). Not permanently established when Europeans arrived but intermittently present by natural incursion/invasion in the 1780s, c. 1830 and in 1845-47 when last known animal was killed for bounty (Dodds et al. 1969). Recent DNA analysis (Wilson et al. 2000) indicates that eastern Canadian wolves are a separate lineage from the western grey wolves and comprise a distinct species (*Canis lycaon*) rather than a subspecies of *C. lupus*.
18. *Canis latrans* Say 1823. Coyote. GREEN (NS). Prehistorically present in New Brunswick (bones from archaeological site on Passamaquoddy Bay dated c. 2000 ybp; Sanger 1987) and probably in NS. Invaded from New Brunswick in late 1970s; common throughout by mid-1980s (Parker 1995).
19. *Alopex lagopus* (Linnaeus 1758). Arctic Fox. An extralimital vagrant (1923, 1935), via ice-floes, to Lingan Bay, Cape Breton Island (De Vany 1923).
20. *Vulpes vulpes* (Linnaeus 1758). Red Fox. GREEN (NS). Common throughout, especially in open habitats.

Family Ursidae (Bears)

21. *Ursus americanus* Pallas 1780. American Black Bear. NOT AT RISK (COSEWIC 1999); GREEN (NS). Common throughout, most abundant in central and western mainland (NS DNR).

Family Procyonidae (Raccoons, Lesser Panda)

22. *Procyon lotor* (Linnaeus 1758). Raccoon. GREEN (NS). Present when Europeans first arrived but disappeared shortly thereafter; reinvaded via Isthmus of Chignecto in 1860s, at which time aboriginal peoples had no memory of its former presence (Gilpin 1870). Now common on mainland, especially in agricultural and suburban/urban residential areas. History on Cape Breton Island uncertain; Cameron (1958) found no evidence of its presence, but introduced populations may have been temporarily established at times between 1918 and 1954 by escapes/ releases from fur farms (Hudgins 1981); recently invaded Cape Breton Island via Canso Strait/Causeway and now occurs as far north as central Victoria Co. (NS DNR).

Family Mustelidae (Weasels, Badgers, Skunks, Otters)
Subfamily Mustelelinae (Weasels, Martens, Ferrets, Polecats)

23. *Martes americana* (Turton 1806). American Marten. RED (NS). A small relict population exists in Cape Breton Highlands (Scott 2001); extirpated on mainland and successfully reintroduced in Kejimkujik National Park in 1987-1994 from northern New Brunswick stock (Scott 1998b).
24. *Martes pennanti* (Erxleben 1777). Fisher. YELLOW (NS). Extirpated by 1922 (Smith 1940); reintroduced in 1947-48 and 1963-66 (Dodds & Martell 1971). Widespread and fairly common in mainland, mostly northwest of a line from Yarmouth to the Canso Causeway (NS DNR).
25. *Mustela erminea* Linnaeus 1758. Ermine (Short-tailed Weasel). GREEN (NS). Common throughout.
26. *Mustela vison* Schreber 1777. American Mink. GREEN (NS). Common throughout, especially near fresh and salt water.
27. *Mustela macrodon* (Prentiss 1903). Sea Mink. EXTINCT (COSEWIC 2000). Disappeared around 1894. Reported to have occurred along southwestern NS coast (Anderson 1946).

Subfamily Mephitinae (Skunks)

28. *Mephitis mephitis* (Schreber 1776). Striped Skunk. GREEN (NS). Historically mainland only, though rare before 1850 (Rand 1933). Abundant on mainland in agricultural areas by 1900; in 1920s began declining drastically from west to east, possibly due to distemper, and was virtually extirpated by 1940s; recolonized the mainland slowly from east to west (Dodds 1969) and now widespread and common. One documented record from southern Cape Breton Island, a roadkilled animal at Glendale, Inverness Co., in 1998 (NS DNR).

Subfamily Lutrinae (Otters)

29. *Lontra canadensis* (Schreber 1776). River Otter. GREEN (NS). Common throughout, in fresh and sometimes salt water.

Family Felidae (Cats)
Subfamily Acinonychinae (Cheetah, Cougar)

30. *Puma concolor* (Linnaeus 1771). Cougar (Puma, Mountain Lion). DATA DEFICIENT (COSEWIC 1998). RED (NS). Some credible sightings/tracks but no photos or specimens. Possibly historically present [in southeast Cape Breton Island] shortly after European arrival (Denys 1672:385-386). Not recorded between then and the late 19th century (Gilpin 1866). Any now in NS would be escaped captive exotic animals, or their descendants (Scott 1998a).

Subfamily Felinae (Typical cats)

31. *Lynx lynx* (Linnaeus 1758). Canada Lynx. Not at risk (COSEWIC 2001); Special Concern (NSESA 2001). Throughout the province in 1860s (Gilpin 1866) but extirpated on mainland by 1930 (Rand 1933); now extremely rare in northern mainland as recent vagrants from Cape Breton Island (NS DNR); increasingly rare and restricted to higher elevations on Cape Breton Island, possibly as result of competition with bobcats, which have invaded recently (Parker 2001).
32. *Lynx rufus* (Schreber 1777). Bobcat (Wildcat). Green (NS). Common on mainland; original status on Cape Breton Island uncertain but not present in 1953 (Cameron 1958); has invaded much of southern Cape Breton Island (NS DNR) since construction of the Canso Causeway.

Family Phocidae (True Seals)

33. *Halichoerus grypus* (Fabricius 1791). Grey Seal. Not at risk (COSEWIC 1999). Locally common on Atlantic, Gulf of St. Lawrence and Bay of Fundy coasts, and on Sable Island where it breeds in large numbers.
34. *Phoca vitulina* Linnaeus 1758. Harbour Seal. Common in all coastal waters except extreme upper Bay of Fundy, where it is occasional. Breeds on rocky coastal islands, and on Sable Island, where numbers have shown a severe decline recently (Stobo 2002).
35. *Phoca groenlandica* Erxleben 1777. Harp Seal. Regular and increasingly frequent visitor to Gulf of St. Lawrence and Atlantic coasts, as late winter/early spring juveniles, and occasionally reaching the upper Bay of Fundy (McAlpine & Walker 1999).
36. *Phoca hispida* Schreber 1775. Ringed Seal. Extralimital vagrant from arctic and subarctic waters, all juveniles or subadults. First recorded on NS mainland at mouth of the Sackville River, Bedford, in 1993 and 1994; 11 records from Sable Island between 1990 and 1998 (Lucas & McAlpine 2002).
37. *Cystophora cristata* (Erxleben 1777). Hooded Seal. Not at risk (COSEWIC 1986). Increasingly frequent visitor to Gulf of St. Lawrence and Atlantic coasts, as late winter/early spring juveniles, and occasionally reaching the upper Bay of Fundy (McAlpine et al. 1999).

Family Odobenidae (Walrus)

38. *Odobenus rosmarus* (Linnaeus 1758). Atlantic Walrus. Extirpated (COSEWIC 2000). Formerly bred on Sable Island and the Magdalen Islands; extirpated by late 1600s (Wright 1989). Now a very rare straggler to NS waters from the eastern Arctic, most recently a juvenile photographed at Cape Sable Island in 1976 (NS MNH) and an unmistakable juvenile seen on rocks off Pt. Pleasant Park, Halifax, on 6 Feb 2000 (NS MNH).

ORDER CETACEA (WHALES)

SUBORDER ODONTOCETI (Toothed Whales)

Family Delphinidae (Dolphins)

39. *Stenella caeruleoalba* (Meyen 1833). Striped Dolphin (Blue Dolphin). Not at risk (COSEWIC 1993). Sable Island (Lucas & Hooker 2000). Common along Continental Shelf edge in summer (Whitehead 2001).
40. *Stenella attenuata* (Gray 1846). Pantropical Spotted Dolphin (Slender-beaked Dolphin). One specimen with no locality data but presumably from Nova Scotian waters (NS MNHC, Sergeant et al. 1970).

41. *Stenella frontalis* (G. Cuvier 1829). Atlantic Spotted Dolphin (Cuvier's Dolphin). One specimen with no locality data but presumably from Nova Scotian waters (NS MNHC, Sergeant et al. 1970).
42. *Delphinus delphis* Linnaeus 1758. Common Dolphin (Short-beaked Common Dolphin). NOT AT RISK (COSEWIC 1991). Common offshore.
43. *Tursiops truncatus* (Montagu 1821). Bottlenose Dolphin. NOT AT RISK (COSEWIC 1993). Bedford Basin 1987 (NS MNHC); West Pennant, Halifax Co. 1993 (MASRD). Occasional offshore in summer (Whitehead 2001).
44. *Grampus griseus* (G. Cuvier 1812). Risso's Dolphin. NOT AT RISK (COSEWIC 1990). Sable Island 1994 (Lawson and Eddington 1998). Occasional off Continental Shelf edge (Whitehead 2001).
45. *Lagenorhynchus albirostris* (Gray 1846). White-beaked Dolphin. NOT AT RISK (COSEWIC 1998). Occasional offshore and common inshore, except extreme upper Bay of Fundy, where it is infrequent.
46. *Lagenorhynchus acutus* (Gray 1828). Atlantic White-sided Dolphin. NOT AT RISK (COSEWIC 1998). Common inshore (including occasional pods in Bedford Basin; P. Brodie 2001) and offshore, except extreme upper Bay of Fundy, where it is infrequent.
47. *Orcinus orca* Linnaeus 1758. Killer Whale (Orca). DATA DEFICIENT (COSEWIC 1999). Economy, Colchester Co., 1950 (Sergeant & Fisher 1957); Sable Island 1972 (Lucas & Hooker 2000). Uncommon, offshore.
48. *Globicephala melas* (Traill 1809). Atlantic Long-finned Pilot Whale. NOT AT RISK (COSEWIC 1994). Common inshore and offshore; strands frequently, sometimes in large numbers.

Family Phocoenidae (Porpoises)

49. *Phocoena phocoena* (Linnaeus 1758). Atlantic Harbour Porpoise (Common Porpoise). THREATENED (COSEWIC 1991). Palka (2000) gives total estimates that suggest a summer population of ~24,900 animals in western NS waters (part of the larger Gulf of Maine-Bay of Fundy population), concentrated within ~70 km of land from Digby around to eastern Shelburne Co. Uncommon or local inshore around remainder of coasts.

Family Monodontidae (Beluga, Narwhal)

50. *Delphinapterus leucas* (Pallas 1776). Beluga (White Whale). ENDANGERED (COSEWIC 1997). Fox Point, St. Margaret's Bay, 1965; Bedford Basin 1968 (Sergeant et al. 1970). Extralimital straggler to NS coastal waters from St. Lawrence Estuary or Labrador. Regular if not resident in the Bay of Fundy in the 1740s, in pods of 30-40 animals (Morris 1748); uncommon there in 19th century (Gilpin 1878) and recently (McAlpine 2001). One initially subadult female (known as "Wilma") lived in Guysborough Harbour from 1993 to 1998 (Frohoff et al. 2000); DNA analysis of her skin scrapings revealed a mitochondrial haplotype known only in belugas from the St. Lawrence Estuary (Gladden et al. 1999).

Family Kogiidae (Dwarf and Pygmy Sperm Whales)

51. *Kogia breviceps* (Blainville 1838). Pygmy Sperm Whale. NOT AT RISK (COSEWIC 1994). Halifax Harbour 1920 (Piers 1923), Sable Island 1969 (Sergeant et al. 1970). Very rare.
52. *Kogia simus* (Owen 1866). Dwarf Sperm Whale. Sable Island, 1971 and 1996 (Lucas & Hooker 2000). Very rare.

Family Physeteridae (Sperm Whale)

53. *Physeter macrocephalus* (Linnaeus 1758). Sperm Whale. Not at risk (COSEWIC 1996). Sable Island 1964 (Sergeant et al. 1970), 1990 (Lucas & Hooker 2000); Petit-de-Grat, Cape Breton Co. 1991; Cherry Hill, Lunenburg Co. 1994; River John, Cumberland Co. 1994 (Reeves & Whitehead 1997); Point Aconi, Cape Breton Co. .1998 (MASRD). One live sighting 20 km NW of Brier Island, 1981 (McAlpine 1985); common offshore in deeper water (Whitehead 2001).

Family Ziphiidae (Beaked Whales)

54. *Hyperoodon ampullatus* (Forster 1770). Northern Bottlenose Whale. Special Concern (Gully population; COSEWIC 1996). Sable Island 1968 (Sergeant et al. 1970); Noel Head, Hants Co., 1969 (Mitchell & Kozicki 1975); Sydney River 1992 (MASRD). Continental shelf/slope waters (Sutcliffe & Brodie 1977). A significant concentration of about 200 animals lives nearly year-round over the Gully, a submarine canyon ~50 km east of Sable Island (Whitehead et al. 1997).
55. *Mesoplodon mirus* True 1913. True's Beaked Whale. Not at risk (COSEWIC 1989). St. Anns Bay, Victoria Co., 1938 (Allen 1939). In deeper water, rare (Whitehead 2001).
56. *Mesoplodon densirostris* (Blainville 1817). Blaineville's Beaked Whale. Not at risk (COSEWIC 1989). Peggys Cove 1940 (Raven 1942); Fourchu Bay 1968 (Sergeant et al. 1970). In deeper water, rare (Whitehead 2001).
57. *Mesoplodon bidens* (Sowerby 1804). Sowerby's Beaked Whale. Special Concern (COSEWIC 1989). Sable Island, 1997 (Lucas & Hooker 2000). In deeper water (Hooker & Baird 1999).

SUBORDER MYSTICETI (BALEEN WHALES)

Family Eschrichtidae (Grey Whale)

58. *Eschrichtius robustus* (Lilleborg 1861). Atlantic Grey Whale. Extirpated (COSEWIC 2000). Continental shelf waters, summering from Cape Cod to Labrador; extirpated by end of 18th century (Reeves & Mitchell 1987).

Family Balaenopteridae (Rorquals)

Most species listed are migratory, and the numbers passing our coasts on northward/southward migration may be much higher than the numbers actually summering in our waters (Brodie 2001).

59. *Balaenoptera acutorostrata* Lacépède 1804. Minke Whale. Common inshore and offshore. Apparently not migratory (Whitehead 2001).
60. *Balaenoptera borealis* Lesson 1828. Sei Whale. Shubenacadie, Hants Co., 1997 (MASRD). Moderately common offshore, very occasional inshore. Possibly not migratory (Whitehead 2001).
61. *Balaenoptera physalus* (Linnaeus 1758). Fin Whale (Finback Whale). Special Concern (COSEWIC 1987). Occasional inshore, especially at mouth of Bay of Fundy and off Halifax; moderately common offshore.
62. *Balaenoptera musculus* (Linnaeus 1758). Blue Whale. Special Concern (COSEWIC 1983). Sable Island 1958 (Sergeant et al. 1970), and 1974 (Lucas & Hooker 2000). Uncommon, offshore only.
63. *Megaptera novaeangliae* (Borowski 1781). Humpback Whale. Special Concern (COSEWIC 1985). Point Michaud, Richmond Co., 2001 (MASRD) Locally common inshore and offshore in summer, especially around southwestern NS.

Family Balaenidae (Right and Bowhead Whales)

64. *Eubalaena glacialis* (Müller 1776). Northern Right Whale. Endangered (COSEWIC 1990). Pugwash, Cumberland Co. 1954 (Sergeant *et al.* 1970); Long Island, 1995 (NS MNHC); a whale floating dead in shipping lanes ~22 km north of Long Island in 1998 was towed ashore there and necropsied (Knowlton & Kraus 2001). An increasing number summers in and near mouth of the Bay of Fundy at the same time as the former large summer concentration on Browns Bank (Winn et al. 1986) has declined; virtually none have been seen there since 1997 (Tobin 2001). Two were seen off Chebucto Head, Halifax Co., in Feb 1987, and one was observed by people on a yacht in Bedford Basin in June 1991 (Brodie 2001). Recent DNA analysis (Rosenbaum et al. 2000) indicates that the North Atlantic and North Pacific populations, formerly considered subspecies, are specifically distinct.

ORDER PERISSODACTYLA (ODD-TOED UNGULATES)

Family Equidae (Horses, Asses, Zebras)

65. *Equus caballus* Linnaeus 1758. Horse (Domestic Horse). A feral population has been established on Sable Island since 1738 (Christie 1980).

ORDER ARTIODACTYLA (EVEN-TOED UNGULATES)

Family Suidae (Pigs)

66. *Sus scrofa* Linnaeus 1758. European Wild Hog (European Wild Boar). Feral on Roberts Island, a fenced private hunting preserve in Yarmouth Co. (NS DNR).

Family Cervidae (Deer, Moose)

67. *Rangifer tarandus* (Linnaeus 1758). Woodland Caribou. Extirpated (NS). The last one was shot on the Cape Breton Highlands in 1921; there have been two failed reintroduction attempts, in the Liscomb Game Sanctuary in 1939 and the eastern Cape Breton Highlands in the late 1960s (Benson & Dodds 1977).
68. *Odocoileus virginianus* (Zimmerman 1780). White-tailed Deer. Green (NS). Present 1000 ybp; absent when Europeans first arrived; reinvaded/reintroduced 1894-1910 (Benson & Dodds 1977). Now common throughout.
69. *Alces alces* (Linnaeus 1758). Moose (American Moose). Red (NS). Extirpated on Cape Breton Island in 1924 and reintroduced from Alberta in 1947-48; now common there. Uncommon to rare on mainland, and declining in some areas, especially in the southwest (Pulsifer & Nette 1995; NS DNR).

ORDER RODENTIA (RODENTS)

Family Sciuridae (Squirrels, Marmots)

70. *Tamias striatus* (Linnaeus 1758). Eastern Chipmunk. Green (NS). Common throughout in drier forest, forest-edge and shrub habitats, especially rocky ones (NS MCRD).
71. *Marmota monax* (Linnaeus 1758). Woodchuck (Groundhog). Green (NS). Hibernates. Common in grassy habitats on mainland, including highway verges in forested regions (NS MCRD). Not yet reported from Cape Breton Island (NS DNR), probably because it is not active in winter and thus cannot use the ice route across the strait.
72. *Sciurus carolinensis* Gmelin 1788. Grey Squirrel. One black specimen reported from Cumberland Co. (Gilpin 1870); repeatedly introduced in the 20th century, once in the Tobeatic Game Sanctuary (Banfield 1974) and often in towns (*e.g.*, Wolfville, Kentville, Halifax, Amherst), but never established (NS MNH).

73. *Tamiasciurus hudsonicus* (Erxleben 1777). American Red Squirrel. GREEN (NS). Common throughout in mixed and coniferous forest and forest-edge habitats of all ages; numbers fluctuate irregularly (NS MCRD). A pair was released on Seal Island in the early 1970s (McLaren 2001) and a population is still present.
74. *Glaucomys volans* (Linnaeus 1758). Southern Flying Squirrel. VULNERABLE (COSEWIC 1988). YELLOW (NS). *Disjunct.* First discovered in Kejimkujik NP in 1971 (Wood & Tessier 1974 – their cited 1962 [not 1967] Acadia University specimen from Pebbleoggitch Lake, catalog no. Ma 541, is actually a small *G. sabrinus*); the upper Gaspereau Valley, Kings Co. in 1984 (Elderkin 1987); Kentville Ravine, Kings Co., in 1998 (NS DNR). Current research by an Acadia graduate student has added 2 new sites within the park, 5 others immediately to the east and southeast outside the park, and documented outlying populations at Bear River and Middleton, Annapolis Co., Falmouth, Hants Co., Cookville, Lunenburg Co. and Ponhook Lake, Queens Co. (Lavers 2001).
75. *Glaucomys sabrinus* (Shaw 1801). Northern Flying Squirrel. GREEN (NS). Common throughout in forest habitats with tree cavities; regularly occupies bird nestboxes in suburban areas adjoining forests (NS MCRD). Often completely syntopic with *G. volans* where the latter occurs (Lavers 2001)

Family Castoridae (Beavers)

76. *Castor canadensis* Kuhl 1820. American Beaver. GREEN (NS). Nearly extirpated by trapping about 1840 but began to recover in southwestern NS by the late 1930s (Smith 1940). Now common throughout in suitable wetlands.

Family Muridae (Typical Voles, Rats, Mice)
Subfamily Arvicolinae (Voles, Lemmings)

77. *Clethrionomys gapperi* (Vigors 1830). Red-backed Vole (Gapper's Red-backed Vole, Southern Red-backed Vole). GREEN (NS). By far the most abundant forest rodent; throughout in all forest, forest-edge and tall shrub habitats (NS MCRD). Populations around Barrington Passage, Shelburne Co., are unique in having a high incidence (14 - 50%) of melanistic animals, usually completely black (NS MCRD).
78. *Synaptomys cooperi* Baird 1858. Southern Bog Lemming. GREEN (NS). Rarely found in bogs in NS; generally rare and very local in forest habitats, especially rocky ones, except on periphery of Cape Breton Highlands where it is fairly common on forested talus slopes (NS MCRD).
79. *Ondatra zibethicus* (Linnaeus 1766). Muskrat. GREEN (NS). Common throughout in wetlands (NS MCRD). Introduced to Seal Island in the early 1990s and now well established (McLaren 2001).
80. *Microtus pennsylvanicus* (Ord 1815). Meadow Vole ("meadow mouse", "field mouse"). GREEN (NS). Common throughout in grass, forb and low shrub habitats, including many inshore islands (NS MCRD). Populations can show extreme fluctuations regionally or locally. The unique population on Bon Portage Island has a high incidence (>50%) of animals with occipital markings ranging from a few white hairs to a 1-cm white blaze (Bondrup-Nielsen 2001), and occasional almost complete leucism (Parsons & Bondrup-Nielsen 1995).
81. *Microtus chrotorrhinus* (Miller 1894). Rock Vole (Yellow-nosed Vole). GREEN (NS). *Disjunct.* Discovered in 1974 (Roscoe & Majka 1976). Locally common on forested talus on periphery of Cape Breton Highlands (NS MCRD).

Subfamily Murinae (Old World Rats and Mice)

82. *Rattus rattus* Linnaeus 1758. Black Rat (Roof Rat). Green (NS). Introduced in many ports and established in some, but did not persist after 1860s. In January 1995 a small breeding population was discovered at Pier 21 in Halifax, the first known occurrence since 1861 (NS MNHC). The rats apparently came from Cuba and were still present and breeding in early 1996, despite control efforts; none have been taken since October 1999 (NS MNH).
83. *Rattus norvegicus* (Berkenhout 1769). Brown Rat (Norway Rat). Green (NS). Introduced. Common in urban and some rural and agricultural areas. Established on Seal Island from a World War II shipwreck (Erskine 1955).
84. *Mus domesticus* Rutty 1772. House Mouse. Green (NS). Introduced. Common in urban and some rural and agricultural areas.

Subfamily Sigmodontinae (New World Rats and Mice)

85. *Peromyscus maniculatus* (Wagner 1845). Deer Mouse. Green (NS). Throughout in forest, forest-edge and tall shrub habitats; tends to be uncommon and local in western mainland where *P. leucopus* also occurs, and absent in coastal strip from Halifax to Digby (NS MCRD). A morphologically and behaviourally distinct population occurs on Isle Haute in the upper Bay of Fundy (Pulsifer 1984).
86. *Peromyscus leucopus* (Rafinesque 1818), subspecies *caudatus* Smith 1939. White-footed Mouse. Green (NS). *Disjunct.* Common in forest, forest-edge and tall shrub habitats from Hants and western Halifax Counties westward, very local in central and eastern NS (Pomquet, Pictou Co. and lower St Mary's River valley, Guysborough Co.); absent from northwest mainland and Cape Breton Island (NS MCRD).

Family Dipodidae (Jerboas, Jumping Mice)
Subfamily Zapodinae (Jumping Mice)

87. *Napaeozapus insignis* (Miller 1891). Woodland Jumping Mouse. Green (NS). Hibernates. Common in moist deciduous and mixed forests and tall shrub habitats throughout, especially along streams.
88. *Zapus hudsonius* (Zimmerman 1780). Meadow Jumping Mouse. Green (NS). Hibernates. Locally common throughout in poorly-drained oldfield, meadow and low shrub habitats.

Family Erethizontidae (New World Porcupines)

89. *Erethizon dorsatum* (Linnaeus 1758). American Porcupine. Green (NS). Common throughout mainland in mixed and coniferous forests; established in eastern Cape Breton Island, probably as a result of human transport (NS DNR).

ORDER LAGOMORPHA (PIKAS, HARES, RABBITS)
Family Leporidae (Hares, Rabbits)

90. *Lepus americanus* Erxleben 1777. Snowshoe Hare (Varying Hare, "rabbit"). Green (NS). Common throughout, with more extreme cyclic fluctuations in Cape Breton Island (Dodds 2001). Introduced to Seal Island in the early 1970s and now common (McLaren 2001).
91. *Lepus timidus* Linnaeus 1758. Arctic Hare. Eight females and four males introduced from Brunette I., Newfoundland, to Scatarie Island, off eastern tip of Cape Breton Island, in 1975; last confirmed present in 1981; none detected in 1987 and 1989 surveys (NS DNR).

Discussion

Nova Scotia's location at mid-latitudes (43° 23′ N to 47° 02′ N) on the east coast of North America has given it elements of both cold temperate and warm temperate mammal communities. Its northeast-to-southwest alignment and narrow connection to the mainland at the midpoint of its length (Fig. 1) have resulted in an unusually high percentage of disjunct species, as past climate zones have shifted north or south, isolating populations at either end of the province. Only three species of mammal (Table 1) have established themselves by invasion through the isthmus in historic times.

This disjunction process has not been limited to mammals. Large numbers of disjuncts also occur in the vascular plants, including 56 Arctic-Alpine (northern) and 21 Coastal Plain (southern) species (Roland 1998). There are many disjunct invertebrates including 10 unionid clams (all NS species also occur in New Brunswick but far from contiguously, and the disjunctions range from only a few watersheds to nearly 700 km (Davis 2002)), 13 butterflies (Layberry et al. 1998) and 13 Odonata (Brunelle 1998). Among the lower vertebrates, 15.6 % of amphibians, 33 % of reptiles (Gilhen 1984) and 25% of our non-diadromous freshwater fishes (Gilhen 2001) are disjunct.

Nova Scotia has six disjunct species of terrestrial mammals (Table 1.), all small insectivores and rodents and all relatively slow dispersers. These comprise 14.3 % of native non-flying terrestrial mammals, 33 % of the insectivores and 18.8 % of native rodents. They represent both northern (Arctic Shrew, Gaspé Shrew, Rock Vole) and southern (Long-tailed Shrew, Southern Flying Squirrel, White-footed Mouse) distributions. These disjunctions are also fairly old (probably several thousands of years, on average) and the isolated populations may harbour significant variants of the species' respective genomes. No other similar-sized area in the United States or Canada has such high proportions of disjunct mammals.

Table I Summary of land-breeding species.

Category	No.	Species
Native species	48	
non-marine	46	
marine (seals)	2	Grey Seal, Harbour Seal
Disjunct species:	6	Arctic Shrew, Gaspé Shrew, Long-tailed Shrew, Southern Flying Squirrel, Rock Vole, White-footed Mouse
Established in wild by invasion:	3	Coyote, Raccoon, White-tailed Deer
Established in wild by introduction:	6	White-tailed Deer, European Wild Hog, Horse, Brown Rat, Black Rat, House Mouse
Introduced but not established:	2	Grey Squirrel, Arctic Hare
Extirpated:	4	Grey Wolf, Atlantic Walrus, Atlantic Grey Whale, Woodland Caribou
Extinct:	1	Sea Mink

Given Nova Scotia's small area and long history of European settlement, its mammal fauna turned out to be very poorly known. The recent completely unexpected discovery of four small mammal species (Gaspé Shrew, Southern Flying Squirrel in 1971, Rock Vole in 1974, Long-tailed Shrew in 1984) was the direct result of systematic and intensive trapping surveys (500 to >1500 trap-nights per site), which had never previously been done in the province. Prior to that, collecting had been carried out by

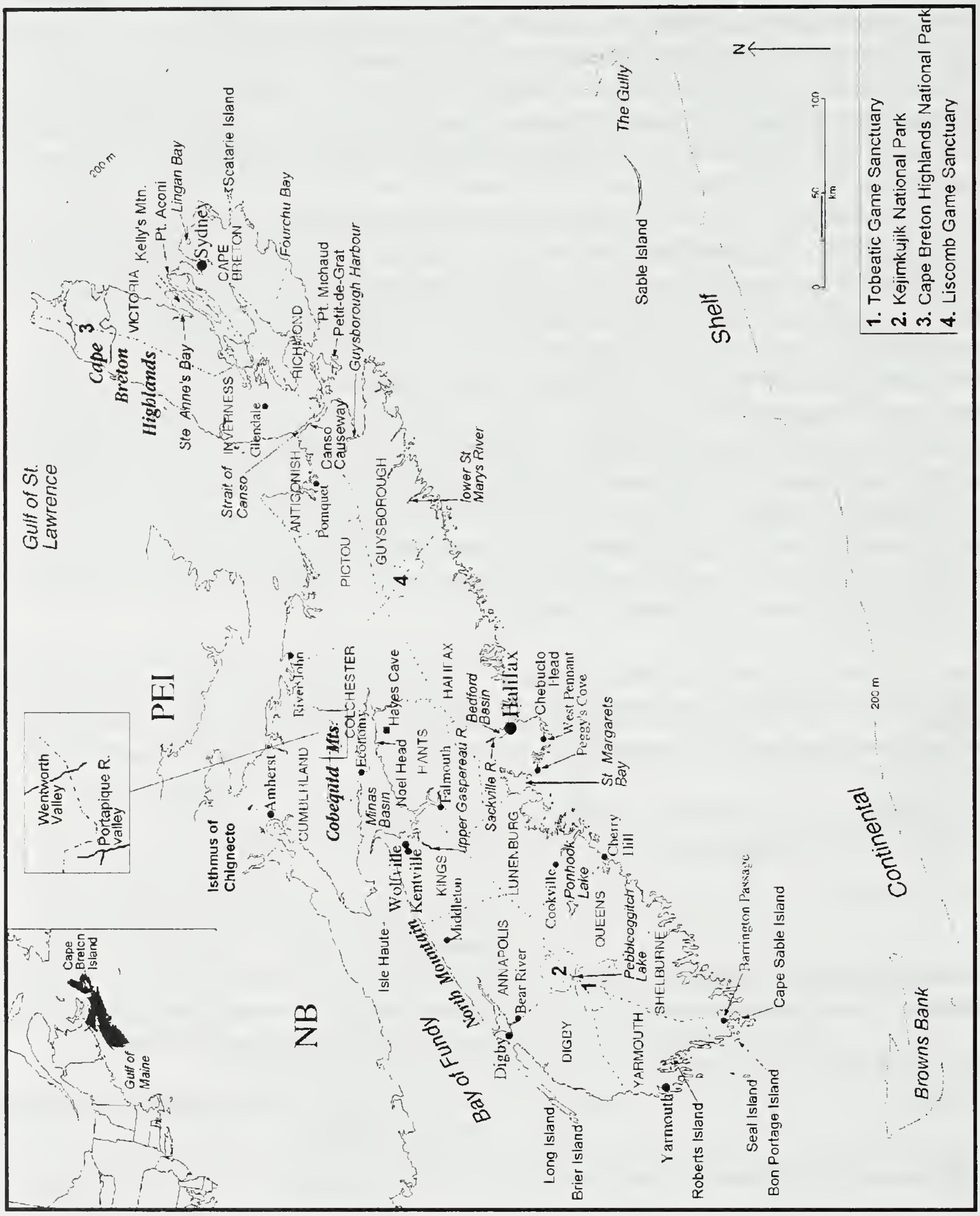

Fig 1 Nova Scotia, showing jurisdictions, geographic features and place names mentioned in the text.

mammalogists working for museums, with the primary goal of producing quality museum specimens, and they had limited their trapping effort to no more than would produce a full day's work of study-skin preparation, or 10 to 12 animals per person. This usually meant in the vicinity of 100-150 traps set per night, which is simply not enough effort to reliably catch the rarest species. In addition, early collectors apparently never trapped the extensive forested talus in the Cobequid Mountains or Cape Breton Highlands (where three of the four new species were found), presumably because it is steep and sometimes dangerous and they had no reason to believe there was anything up there that they could not also find where the going was easier and safer.

Cape Breton Island has historically had a depauperate mammal fauna (Cameron 1958), lacking 8 species that were present on the adjacent mainland (Arctic Shrew, Smoky Shrew, Bobcat, Striped Skunk, Raccoon, White-footed Mouse, Woodchuck, Porcupine). The building of the Canso Causeway across the Strait of Canso in 1953-55 had a major zoogeographic impact, as it caused the western third of the strait to freeze over in winter and allowed the invasion and establishment on Cape Breton Island of four large mammal species (Coyote, Raccoon, Striped Skunk and Bobcat) and the perhaps temporary reoccupation of the mainland by one (Canada Lynx). Woodchucks, being hibernators, have not been able to use the frozen strait as an invasion route; if they are to colonize Cape Breton Island on their own it will have to be via the causeway itself, which is not likely to happen since the 1.2-km paved roadway is bordered only by virtually unvegetated loose boulders.

The mammal list is not necessarily complete. There is a slight possibility that another species, the Northern Bog Lemming (*Synaptomys borealis*), occurs at higher elevations in the Cape Breton Highlands. Its distribution is very similar to that of the Rock Vole (*Microtus chrotorrhinus*), with populations on the north shore of the Gulf of St. Lawrence, and in the Gaspé Peninsula and northern New Brunswick (Banfield 1974). It prefers Black Spruce bogs, which occur extensively on the highlands (Davis & Browne 1996).

There are still major gaps in our knowledge of some mammal distributions as well. For example, there are very extensive forested talus slopes on the eastern end of North Mountain which are suitable habitat for the Long-tailed Shrew (Woolaver et al. 1998) but we do not yet know if it occurs there. There also may be additional fragmented populations of White-footed Mouse on the eastern mainland.

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DO WE KNOW BEETLES? LESSONS FROM NEW RECORDS OF CERAMBYCIDAE (COLEOPTERA) FOR NOVA SCOTIA

DAVID B. McCORQUODALE[1*] and SØREN BONDRUP-NIELSEN[2]
[1]*Department of Behavioural and Life Sciences*
University College of Cape Breton
Sydney, Nova Scotia, B1P 6L2
[2]*Department of Biology*
Acadia University
Wolfville, Nova Scotia, B0P 1X0

The long-horned beetles (Coleoptera: Cerambycidae) are taxonomically relatively well known in North America and can potentially serve as an important forest biomonitoring tool. For such a tool to work accurate distributional data are required. We compared the status of cerambycids for Nova Scotia based on specimens in collections with two recent compilations that include distributional information, one for Canada and one for northeastern North America. We found major discrepancies. The two compilations reported a total of 55 species, while 87 species were in the collections examined. An accurate and up to date inventory is essential. This is underscored by the recent concern for the "invasion" of the Brown Spruce Long-horn Beetle, *Tetropium fuscum*, in Nova Scotia that was first collected more than 10 years ago, but misidentified. Both regional and national collections need to be supported to ensure effective strategies for conservation and forest management.

En Amérique du Nord, les longicornes (Coléoptères : Cérambycidés) sont assez bien connus sur le plan taxinomique et pourraient constituer un outil important dans la surveillance biologique des forêts. Pour qu'un tel outil soit efficace, il faut disposer de données précises sur la répartition des insectes. Nous avons comparé la situation des Cérambycidés de la Nouvelle-Écosse, établie à partir de spécimens de collections, à deux compilations récentes qui comprennent des données relatives à la répartition, à savoir une pour le Canada (Bousquet, 1991) et une pour le nord-est de l'Amérique du Nord (Dowie et Arnett, 1996). Nous avons découvert des différences notables. Les deux compilations font état d'un total de 55 espèces, tandis que 85 espèces ont été recensées dans les collections examinées. Il est essentiel d'effectuer un inventaire précis et à jour. Cette nécessité est soulignée par le problème récent de l'« envahissement » du longicorne brun de l'épinette (*Tetropium fuscum*) en Nouvelle-Écosse, qui avait été récolté pour la première fois il y a plus de 10 ans, mais mal identifié. Il faut soutenir les collections régionales et nationales pour assurer le succès des stratégies de conservation et d'aménagement des forêts.

Introduction

The long-horned wood boring beetles, the family Cerambycidae, are relatively well known in North America. The taxonomy, identification, natural history, economic impact and distribution are well known compared to most other groups of beetles. The revisions by Linsley and Chemsak provide a comprehensive and solid taxonomic foundation for the family (Linsley 1962a, 1962b, 1963, 1964, Linsley & Chemsak 1972, 1976, 1984, 1995, 1997, Chemsak 1996). The recent pictorial field guide by Yanega (1996) set out to provide a tool so that non-specialists could identify cerambycids in northeastern North America to species. Yanega (1996) produced his field guide because of his view that cerambycids offered one of the best opportunities for forest biomonitoring by non-professionals. He argued that cerambycids would be an excellent choice because they are not plants, they can be sampled adequately and they have the potential to be reasonable indicators of habitat differences. As consumers of wood, cerambycids have attracted the attention of applied entomologists and foresters, resulting in many studies on their biology and relations with plants (reviewed in Linsley

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* Author to whom correspondence should be addressed.

1961, Baker 1972, Safranyik & Moeck 1995, Yanega 1996). Cerambycids include some of the largest and most colourful beetles in North America. As a result insect collectors have pursued them and they are well represented in collections. These collectors have provided the impetus and data for comprehensive lists for some areas (e.g Gosling 1973, Gosling & Gosling 1977, Laplante et al. 1991, Dearborn & Donahue 1993). However, no such comprehensive list is available specifically for Nova Scotia. The occurrence of species of cerambycids in Canadian provinces and the northeastern United States, has been compiled twice recently, by McNamara in the 'Checklist of Beetles of Canada and Alaska' (Bousquet 1991) and more recently by Downie & Arnett (1996) in 'The Beetles of Northeastern North America'.

We became interested in wood boring beetles through projects designed to study the influence of land use and forestry practices on beetles (e.g. Kehler et al. 1996). As soon as we started identifying Cerambycidae collected in Nova Scotia we realized that many of the species we were collecting were not recorded in the two recent compilations. A first step in species level conservation is a reasonable inventory. The inventory provides the basis to check for species with low populations or vulnerable status. An inventory is also important in the ability to detect invasive species, which may cause widespread ecological problems. Without attention to a basic inventory, it is difficult to have the expertise available to recognize recent invaders. The importance of this has been underscored in Nova Scotia with the recent recognition of the Brown Spruce Long-horn Beetle, *Tetropium fuscum*, despite it being in the province for more than a decade (Forestry Canada 2000, Smith & Hurley 2000).

We therefore set out to assess the strengths and weaknesses of the two recently published compilations by comparing these lists with the cerambycids in six small insect collections within the province of Nova Scotia and four larger collections in central Canada. We report here new information on the occurrence of cerambycids in Nova Scotia and we make suggestions for better distribution of information and better use of extant natural history collections.

Methods

All pinned specimens of Cerambycidae from Nova Scotia were examined in five insect collections in Nova Scotia, Acadia University (ACAD), Nova Scotia Department of Natural Resources (NSDNR), Nova Scotia Museum of Natural History (NSMNH), St. Francis Xavier University (STFXU) and University College of Cape Breton (UCCB), between 1996 and 1998. All pinned specimens of Cerambycidae from Nova Scotia in the collections of the Royal Ontario Museum (ROM), Toronto, Ontario, Canadian Museum of Nature (CMN), Aylmer, Quebec, Canadian National Collection of Insects, Arachnids and Nematodes, Agriculture and Agri-Food Canada, Ottawa (CNCI) and the Canadian Forestry Service, Atlantic Forestry Centre, Fredericton (CFSF) were examined in 1997 and 1998. All specimens were either identified or previous identifications confirmed using Yanega (1996), supplemented by the revisions by Linsley (1962a,b, 1963, 1964) and Linsley & Chemsak (1972, 1976, 1984, 1995) and references therein. Nomenclature and taxonomy follows Yanega (1996).

The list of species found in the collections was compared with two lists for Nova Scotia: McNamara's (1991) list of Cerambycidae in 'Checklist of Beetles of Canada and Alaska' and Downie & Arnett's (1996) 'The Beetles of Northeastern North America'. A more recent online version of Bousquet (1991) is available through the CNCI website, but it does not include any additions to the list of Cerambycidae for Nova Scotia.

Data from the label of each specimen of species not included in McNamara (1991) is presented in the form: county, locality, date or range of dates collected, collector, number of specimens if more than one, and institution. Other information on the label is not generally included. Since the county was not included on most labels, in most cases the county is implied from the locality information.

Results

The survey of collections revealed specimens of 87 species of Cerambycidae from Nova Scotia based on examination of about 1500 specimens. This compares with totals of 51 species from Nova Scotia in 'The Checklist of Beetles of Canada and Alaska' (McNamara 1991) and 23 species in 'The Beetles of Northeastern North America' (Downie & Arnett 1996). The total number of species reported for Nova Scotia is 91, including species not seen in any of the collections. No specimens of three of the 51 species in McNamara (1991) were seen: *Semanotus ligneus, Xylotrechus quadrimaculatus* and *Typocerus acuticauda.* One of these, *T. acuticauda*, is included from Nova Scotia in Downie & Arnett (1996). Additionally Downie & Arnett (1996) report *Brachyleptura vagans* from Nova Scotia and no specimens were found. Downie & Arnett (1996) include five species that are not on McNamara's (1991) list that were found in the collections: *Anthophylax cyaneus, Pygoleptura nigrella, Sachalinolobia rugipennis, Clytus ruricola,* and *Aegomorphus modestus.*

In Section I below, 39 species not included in McNamara (1991) and data supporting their occurrence in Nova Scotia are listed. Label data for all specimens are included for species with fewer than 10 records. For species with more than 10 records, only the number of records for each county is included. In Section II we list the species included in either McNamara (1991) or Downie & Arnett (1996), but are not represented by specimens in the collections examined.

I. Species not reported for Nova Scotia in 'Checklist of the Beetles of Canada and Alaska'

Aseminae

Asemum striatum (Linné)
Thirty one records and 58 specimens from Antigonish (1), Cape Breton (1), Colchester (9), Cumberland (2) Guysborough (2), Halifax (8), Hants (4), and Lunenburg (4) Counties

This species is widespread in North America, from the Yukon to Florida, wherever there are coniferous trees (Chemsak 1996). McNamara (1991) reports it from New Brunswick and Newfoundland in Atlantic Canada, while Downie & Arnett (1996) do not record it from Atlantic Canada or northern New England. From the specimens available, it appears to be widespread in Nova Scotia, as would be expected from a province with large stands of its hosts, spruce (*Picea* spp.) and balsam fir (*Abies balsamea*) (Chemsak 1996, Linsley & Chemsak 1997).

Tetropium fuscum (Fabricius)
Halifax, Point Pleasant Park, 22 June 1990, Ballard, R, NSMNH
Halifax, Point Pleasant Park, 22 June 1990, Robertson, S, NSMNH
Halifax, Point Pleasant Park, 28 June 1990, Harding, G, 3, NSMNH
Halifax, Point Pleasant Park, 29 June 1990, Robertson, S, 11, NSMNH

This species is widely distributed in northern Europe (Bily & Mehl 1989) and only known from the Halifax area in North America (Forestry Canada 2000, Smith & Hurley 2000). These specimens were collected during a project designed to assess the impact of bark beetles on the health of spruce trees in Point Pleasant Park (Robertson 1990). Originally they were identified as the very similar congener, *T. cinnamopterum* and about ten years later it was realized they were a European species (Forestry Canada 2000, Smith & Hurley 2000). This species has been the focus of an eradication program and surveys to determine the extent of its distribution in Nova Scotia were undertaken in 2000 and 2001. Reports from the Canadian Forestry Service and the Canadian Food Inspection Agency, the two bodies responsible for this work, should be consulted for up to date information on its status in the Halifax area (Forestry Canada 2000).

Tetropium schwarzianum Casey
Halifax, Point Pleasant Park, 29 June 1990, Robertson, S, NSMNH

This species is widely distributed, but not common, from Minnesota east and south to North Carolina and a record for southern Nova Scotia is included on the distribution map in Chemsak (1996). McNamara (1991) reports it from Ontario, Quebec and Newfoundland. Downie & Arnett (1996) do not record it in Atlantic Canada or northern New England, although it is known from Maine (Dearborn & Donahue 1993). We have seen only the one specimen from Halifax, presumably different from the record in Chemsak (1996). Larvae feed on pines, *Pinus* spp. (Chemsak 1996). The specimen from Point Pleasant Park was collected during a survey of bark beetles in this urban park (Robertson 1990).

Lepturinae

Desmocerus palliatus (Forster)
Cumberland, Amherst, 14 June 1992, Ogden, J, 2, NSDNR

There are records of this species from Newfoundland and New Brunswick in Atlantic Canada (McNamara 1991). Downie & Arnett (1996) include reports from two states in northern New England. Larvae feed on the roots of the Common Elderberry, *Sambucus canadensis* (Linsley & Chemsak 1972), which is more common in central Nova Scotia, than elsewhere in the province (Roland 1998).

Acmaeops proteus proteus (Kirby)
Colchester, Masstown, 29 June 1990, Smith, TD, NSDNR
Colchester, Masstown, 6 July 1990, Smith, TD, NSDNR
Hants, Mount Uniacke, 14 June 1952, Ferguson, DC, NSMNH
Hants, Stanley, 24 June 1992, Ogden, J, NSDNR

This is a widespread species, known from Alaska to New Brunswick, Labrador and Newfoundland (McNamara 1991). Downie & Arnett (1996) record it only from Newfoundland in Atlantic Canada. Larvae feed under the bark of a variety of conifers (Linsley & Chemsak 1972).

Analeptura lineola (Say)
Cumberland, East Leiscester, 28 June 1995, Corkum, C, ACAD
Guysborough, Melopseketch Lake, 28 June 1995, Corkum, C, ACAD
Guysborough, Borseo, 13 July 1995, Corkum, C, ACAD

McNamara (1991) reports this species from Ontario, Quebec and New Brunswick in Canada, while Linsley & Chemsak (1976) describe the range as "Ontario to Florida to midwestern states". Dearborn & Donahue (1993) state that it is found statewide and has been collected from balsam fir, pine and on blossoms of sumac. Downie & Arnett (1996) do not include any reports from Atlantic Canada or northern New England. Larvae feed on birch, other hardwoods and pines (Linsley & Chemsak 1976, 1997, Yanega 1996).

Anastrangalia sanguinea (LeConte)
Colchester, Debert, 16 July 1992, Georgeson, E, NSDNR

This is another widespread species across northern North America, known from Alaska to New Brunswick and reported for New Brunswick (Downie & Arnett 1996). It is known from many places in Maine where it has been collected from balsam fir (Dearborn & Donahue 1993). Pines are the hosts through much of its range (Linsley & Chemsak 1972).

Anthophylax cyaneus (Haldeman)
Nineteen records, 21 specimens, from the Counties of Colchester (2), Cumberland (3), Guysborough (2), Halifax (4), Inverness (2), Lunenburg (4), Pictou (1), and Yarmouth (1).

McNamara (1991) reports this species only from Ontario, Quebec and New Brunswick. Downie & Arnett (1996) include records from Nova Scotia as well as two states in northern New England. Larvae are catholic in their choice of food, using hardwoods of many species and probably some conifers as well (Linsley & Chemsak 1972).

Brachyleptura rubrica (Say)
Pictou, Pictou, 8 July 1942, Ferguson, DC, NSMNH
Pictou, Pictou, 18 July 1942, Ferguson, DC, NSMNH

This species was known from Ontario, Quebec and New Brunswick (McNamara 1991) and from Maine (Dearborn & Donahue 1993). However Downie & Arnett (1996) did not report it from Atlantic Canada or northern New England. Larvae feed on decaying hardwoods (Linsley & Chemsak 1972, 1997), probably beech (*Fagus grandifolia*) and oak in Nova Scotia.

Gnathacmaeops pratensis (Laicharting)
Cape Breton, Sydney, UCCB, 14 July 1986, Tynski, S, UCCB
Colchester, Masstown, 15 June 1990, Smith, TD, NSDNR
Cumberland, Amherst, 25 June 1994, Ogden, J, NSDNR

This is another species that is widespread across northern North America, known from Alaska to New Brunswick, Labrador and Newfoundland (McNamara 1991). Downie & Arnett (1996) record it from Maine, but not from Atlantic Canada. The larvae feed on conifers (Linsley & Chemsak 1972).

Leptura plebeja Randall
Cape Breton, Georges River, 31 July 1996, McCorquodale, DB, UCCB
Inverness, Kenloch, 12 Aug 1991, Slade/Rolfe, UCCB

This species was known from Manitoba through to New Brunswick (McNamara 1991) and Downie & Arnett (1996) report it from New Brunswick and Maine. The larvae feed on conifers (Linsley & Chemsak 1972). It is one of the few cerambycids reported to use Red Spruce, *Picea rubens*, as a host (Linsley & Chemsak 1997). The two specimens from Nova Scotia are from Cape Breton Island where Red Spruce is very rare.

Lepturopsis biforis (Newman)
Cape Breton, Sydney, UCCB, 19 August 1985, Tynski, S, UCCB
Digby, Belliveau, 2 August 1984, Neil, K, NSMNH
Hants, Uniacke, 29 August 1968, Doleman, P, NSMNH
Inverness, Cranton Section, 24 August 1959, no data, CFSF

This species is known from Ontario, Quebec and New Brunswick (McNamara 1991) and from Maine (Dearborn & Donahue 1993). However Downie & Arnett (1996) did not report it from Atlantic Canada or northern New England. Larvae feed on both hardwoods and conifers (Linsley & Chemsak 1972).

Pygoleptura nigrella (Say)
Guysborough, Archibald Mills, 19 July 1994, Kehler, D, ACAD

This is a widespread species across northern North America from Alaska to New Brunswick, Labrador and Newfoundland (McNamara 1991). Downie & Arnett (1996) report it from Nova Scotia and Newfoundland in Atlantic Canada and Maine in northern New England. Larvae feed on decaying conifers (Linsley & Chemsak 1976, 1997).

Rhagium inquisitor (Linné)
Forty four records, 59 specimens, from Antigonish (2), Cape Breton (4), Colchester (7), Cumberland (1), Guysborough (1), Halifax (14), Hants (3), Inverness (1), Lunenburg (7), Pictou (2), and Queens (2) Counties

This is a widespread species with a wide distribution in Europe and across northern North America from the Yukon to Newfoundland (Linsley & Chemsak 1972, McNamara 1991). Downie & Arnett (1996) do not record it from Atlantic Canada or northern New England. The larvae feed on the cambium of a variety of conifers (Linsley & Chemsak 1972, 1997).

Sachalinobia rugipennis rugipennis (Newman)
Victoria, north of Wreck Cove Reservoir, 13 June 1996, 2, Lauff, R, STFXU
Halifax, Tomahawk Lake, May 1970, Doleman, P, Gilhen, J, NSMNH

This species has a northern distribution with records from Manitoba to New Brunswick in Canada (McNamara 1991). Downie & Arnett (1996) report it for both New Brunswick and Nova Scotia and all three states in northern New England. The larvae feed on spruce and pine (Linsley & Chemsak 1972).

Cerambycinae

Enaphalodes rufulus (Haldeman)
Lunenburg, Bridgewater, 20 July 1949, Ferguson, DC, NSMNH

This species was reported from Ontario and Quebec in Canada (McNamara 1991, Linsley 1963). Downie & Arnett (1996) did not record it from Atlantic Canada, but did record it in New Hampshire, as far north as the map in Linsley (1963) illustrates the range. The larvae feed primarily on branches of living Red Oak, *Quercus rubra* (Baker 1972). Red Oak is widespread in Nova Scotia and grows in the Bridgewater area (Hosie 1990, Roland 1998).

Anelaphus parallelus (Newman)
Annapolis, Annapolis Royal, 13 June 1949, Ferguson, DC, 21, NSMNH
Annapolis, Annapolis Royal, 17 June 1949, Ferguson, DC, 2, NSMNH
Kings, Kentville, 08 August 1911, Frost, CP, ROM

Lunenburg, Bridgewater, 28 May to 5 June 1965, Wright, B, NSMNH
Lunenburg, Bridgewater, 30 June 1965, Dept of Forestry, 4, NSMNH
Lunenburg, Bridgewater, 30 June 1965, Wright, B, 6, NSMNH
Lunenburg, Bridgewater, July 1965, no data, 6, CFSF
Queens, Tobeatic Game Sanctuary, 12 March 1953, no data, 4, CFSF
Queens, no location, 03 March 1944, no data, CFSF

This species is recorded in Canada from Manitoba to Quebec (McNamara 1991). Downie & Arnett (1996) do not include records from Atlantic Canada or northern New England, although it is known from Maine (Dearborn & Donahue 1993). The northern most locations on the range map in Linsley (1963) are in central Massachusetts and eastern Ontario. Larvae feed on twigs of a wide variety of deciduous trees and shrubs, with a preference for oak (Linsley 1963).

Anelaphus villosus (Fabricius)
Annapolis, Lake Kejimkujik, 9 August 1961, Ferguson, DC, NSMNH

This species is recorded in Canada from Manitoba to Quebec (McNamara 1991). Downie & Arnett (1996) do not include records from Atlantic Canada or northern New England, although it is known from Maine (Dearborn & Donahue 1993). The northeastern most locations on the range map in Linsley (1963) are in eastern Ontario, eastern New York and western Massachusetts. Like its congener, larvae feed on twigs of a wide variety of deciduous trees and shrubs (Linsley 1963).

Molorchus bimaculatus bimaculatus Say
Guysborough, Salem Lake, 15 to 30 June 1997, Bishop, DJ, ACAD
Lunenburg, Bridgewater, 19 June 1965, Wright, B, 4, NSMNH
Lunenburg, Bridgewater, 30 June 1965, Wright, B, 3, NSMNH

This species is known from Alberta east to Quebec in Canada (McNamara 1991). Downie & Arnett (1996) report it to be widespread in the northern New England and Atlantic Canada. The Bridgewater specimens were collected in window trap in Red Oak, *Quercus rubra*. The larvae of this subspecies feed on a wide variety of deciduous trees and shrubs (Linsley 1963).

Phymatodes dimidiatus (Kirby)
Inverness, Whycocomagh, 9 July 1967, Wright, B, 2, NSMNH
Inverness, Whycocomagh, 20 July 1980, Wright, B, NSMNH
Hants, Stanley, 8 July 1982, Leblanc, M, NSDNR

This species has a mainly western distribution (Linsley 1964), but is known from Alaska to as far east as New Brunswick in Canada (McNamara 1991). Downie & Arnett (1996) do not record it from Atlantic Canada or northern New England, although it is known from Maine (Dearborn & Donahue 1993). Larvae live under the bark of coniferous trees (Linsley 1964).

Phymatodes testaceus (Linné)
Halifax, Halifax, 20 August 1992, Yarn, B, 7, NSMNH, firewood in basement
Lunenburg, Petite Riviere, 10 July 1957, Ferguson, DC, NSMNH,
Lunenburg, Petite Riviere, 12 July 1957, Ferguson, DC, 3, NSMNH,
Lunenburg, Chester, 16 July 1969, Wright, B, NSMNH,
Lunenburg, Big Mushamush Lake, 30 June 1979, Wright, B, NSMNH,
Lunenburg, Sunnybrook, 19 July 1992, Wright, B, 12, NSMNH, firewood in basement

In Canada, this species has been recorded only from Quebec and Ontario (McNamara 1991). Downie & Arnett (1996) do not record it from Atlantic Canada or northern New

England, although it is known from Maine (Dearborn & Donahue 1993). This is a holarctic species with a wide range in Europe, North Africa and North America (Linsley 1964). Larvae live under the bark of a variety of hardwoods, especially oak (Linsley 1964).

Megacyllene robiniae (Forster)
Ten records, 24 specimens, from Colchester (2), Halifax, (6) and Kings (2) Counties

This species is known from Ontario and Quebec in Canada (McNamara 1991). Downie & Arnett (1996) do not record it from Atlantic Canada or northern New England, although it is known from Maine (Dearborn & Donahue 1993). The host is the ornamental Black Locust, *Robinia pseudoacacia*, which has been widely planted in Nova Scotia (Roland 1998). Most records are of adults reared from ornamental trees.

Glycobius speciosus (Say)
Colchester, Brookfield, 22 July 1985, Sutherland, P, NSDNR
Colchester, Stewiacke, 22 July 1979, McLennan, G, NSMNH
Cumberland, Springhill, 12 August 1943, TKB Collection, NSMNH
Halifax, Portuguese Cove, 05 August 1986, Purcell, M, 2, NSMNH
Kings, Kentville, 12 July 1979, no data, NSMNH

The Sugar Maple Borer is known from Ontario and Quebec in Canada (McNamara 1991). Downie & Arnett (1996) do not record it from Atlantic Canada or northern New England, although it is known from Maine (Dearborn & Donahue 1993). The larvae feed on Sugar Maple (*Acer saccharum*) (Linsley 1964).

Calloides nobilis (Harris)
Lunenburg, Bridgewater, 27 June 1993, Selig, GD, NSMNH

McNamara (1991) records this species from Ontario and Quebec in Canada. Downie & Arnett (1996) do not record it from Atlantic Canada or northern New England, although there are two records for Maine (Dearborn & Donahue 1993). Larvae feed on hardwoods including ash and oak (Linsley 1964). This specimen was brought to a museum in Lunenburg County and the details of its capture are not clear.

Xylotrechus annosus annosus (Say)
Cumberland, Springhill, 1 June 1954, Gray, RD, NSMNH
Halifax, Elderbrook, 6 June 1996, Ogden, J, NSDNR

This species has a wide range across Canada from the North West Territories to New Brunswick (McNamara 1991, Linsley 1964). Downie & Arnett (1996) record it in New Brunswick and Maine. Willow and poplar are the host plants (Linsley 1964).

Xylotrechus colonus (Fabricius)
Cumberland, Parrsboro, 17 August 1996, Ogden, J, NSDNR
Halifax, Halifax, 20 April 1974, Wright, B, NSMNH
Lunenburg, Lunenburg, 5 February 1973, Wright, B, NSMNH
Lunenburg, Canaan, 4 January 1985, Hirtle, C, NSMNH
Victoria, Baddeck, 20 June 1993, no data, NSDNR

In Canada, this species was known from Manitoba to New Brunswick (McNamara 1991) and Downie & Arnett (1996) reported it from three states in Northern New England. Three of the Nova Scotia records are of adults that emerged from firewood during the winter or early spring. Therefore the specific location where these individuals lived is unknown. Larvae feed on a wide variety of deciduous trees (Linsley 1964).

Clytus ruricola (Olivier)
Eleven records, 13 specimens from Cape Breton (1), Colchester (3), Cumberland (1), Lunenburg (3), Pictou (1), Richmond (1) and Victoria (1) Counties

This is a widespread species in Canada with records from Alberta to New Brunswick (McNamara 1991, Linsley 1964). Downie & Arnett (1996) report it from Nova Scotia plus two states in northern New England. Larvae feed on the wood of many species of deciduous trees, including maples and birches (Linsley 1964).

Lamiinae

Psenocerus supernotatus (Say)
Queens, Lake Kejimkujik, 2 July 1957, Ferguson, DC, NSMNH

In Canada, this species is known from Manitoba to New Brunswick (McNamara 1991) and Downie & Arnett (1995) report it from Maine and Vermont in northern New England. Larvae feed on a wide variety of deciduous shrubs and trees (Linsley & Chemsak 1984, 1997).

Pogonocherus mixtus Haldeman
Lunenburg, Chester, 5 August 1991, Georgeson, E, NSDNR

This is a widespread species in North America, known from the Yukon to New Brunswick in Canada (McNamara 1991). Downie & Arnett (1996) report it from three states in northern New England, but not from Atlantic Canada. Larvae feed on both conifers and some deciduous shrubs (Linsley & Chemsak 1984, 1997).

Aegomorphus modestus (Gyllenhal)
Digby, Lake Kejimkujik NP, 9 Aug 1961, no data, NSMNH
Digby, Lake Kejimkujik, 3 July 1968, Wright, B, NSMNH
Kings, Centreville, 23 July 1949, Ferguson, DC, NSMNH
Kings, Kentville, 17 July 1985, Neil, K, NSMNH
Lunenburg, Big Mushamush Lake, 4 August 1976, 2, Wright, B, NSMNH

This species is known from Manitoba, Ontario and Quebec in Canada (McNamara 1991) and from two states in northern New England (Downie & Arnett 1996). Larvae feed on a wide variety of deciduous trees (Linsley & Chemsak 1984, 1997).

Astylopsis sexguttata (Say)
Hants, Mount Uniacke, 1 August 1968, 1, Wright, B, NSMNH
Nova Scotia, County unknown, St George, 09 August 1939, no data, CFSF

This species is known from Manitoba, Ontario and Quebec in Canada (McNamara 1991). It is not recorded from northern New England or Atlantic Canada in Downie & Arnett (1996). Larvae feed on a variety of conifers (Linsley & Chemsak 1995, 1997).

Sternidius variegatus (Haldeman)
Antigonish, Brierly Beach, 12 July 1956, Ferguson, DC, NSMNH
Inverness, Margaree Forks, 26 July 1991, Georgeson, E, CNCI
Inverness, Margaree Forks, 22 August 1995, Ogden, J, NSDNR
Victoria, Baddeck Bridge, 29 July 1970, Wright, B, 2, NSMNH

This is a widespread species, known from Alberta to New Brunswick in Canada (McNamara 1991) and Maine (Dearborn & Donahue 1993). Downie & Arnett (1996) do not record it from Atlantic Canada or northern New England. Larvae feed on a wide variety of trees and shrubs (Linsley & Chemsak 1995, 1997).

Urographis fasciatus (DeGeer)
Lunenburg, Big Mushamush Lake, 21 July 1978, Wright, B, NSMNH
Lunenburg, Riverport, 26 July 1987, Corkum, K, NSMNH
Queens, White Point Beach, 8 September 1954, Ferguson, DC, NSMNH
Queens, Kejimkujik National Park, SI/MAB Plot, 11 July 1994, no data, CFSF

This species is reported from Ontario and Quebec in Canada (McNamara 1991) and from two states in northern New England in Downie & Arnett (1996), but not from Atlantic Canada. Larvae feed on a wide variety of trees and shrubs (Linsley & Chemsak 1995, 1997).

Saperda calcarata Say
Fifty seven records, 72 specimens from Annapolis (1), Cape Breton (2), Colchester (12), Cumberland (9), Digby (1), Halifax (11), Hants (1), Inverness (2), Kings (2), Lunenburg (4), Pictou (2), Queens (5), Shelburne (2), Victoria (1), and Yarmouth (2) Counties

This is a widespread species known from British Columbia to Quebec in Canada (McNamara 1991). It is one of the few cerambycids reported from Prince Edward Island (McNamara 1991). The range map in Linsley & Chemsak (1995) shows records from New Brunswick and Prince Edward Island. Downie & Arnett (1996) report it from Labrador in Atlantic Canada and from two states in northern New England. The larvae feed on willow and poplar (Linsley & Chemsak 1995, 1997).

Saperda populnea moesta LeConte
Cape Breton, Sydney Tar Ponds, 13 June 1996, Hudson, LA, UCCB
Cape Breton, Sydney Tar Ponds, 28 June 1996, Hudson, LA, UCCB
Victoria, Dingwall, 15 June 1983, Bousquet, Y, CNCI

This is a widespread species known in Canada from the Yukon to Quebec (McNamara 1991). This species is not recorded from Atlantic Canada or northern New England in Downie & Arnett (1996). The larvae feed on twigs of willow and poplar (Linsley & Chemsak 1995, 1997).

Saperda tridentata Olivier
Eleven records, 17 specimens, Colchester (1), Cumberland (1), Halifax (1), Inverness (4), Kings (1), Pictou (1) and Victoria (2) Counties

This species is known from Saskatchewan to Quebec in Canada (McNamara 1991). Although they do not record it from Atlantic Canada, it is reported from two states in northern New England in Downie & Arnett (1996). The larvae feed on elm (Linsley & Chemsak 1995, 1997).

Oberea deficiens Casey
Kings, Lake Gg (George), 8 July 1948, Archibald, KD, NSMNH

This species is recorded from Ontario and Quebec in Canada (McNamara 1991). Yanega (1996) documented some of the problems associated with identification of *Oberea* spp. and distinguished between this taxon and the similar *O. praelonga* and *O. ulmicola*. This species is not included in either Downie & Arnett (1996) or Linsley & Chemsak (1995). This species appears to feed exclusively on viburnums (Yanega 1996).

Oberea pallida Casey
Halifax, Dartmouth, Cole Harbour, 28 July 1977, Hicks, SD, CNCI
Richmond, Grand River, 16 August 1931, Smith, CC, CFSF

This species is known from Manitoba, Ontario and Quebec in Canada (McNamara 1991). Yanega (1996) clarified how to identify this species and showed that identifications reported in Linsley & Chemsak (1995) are not reliable. The Cole Harbour specimen was caught on alder, the host according to Yanega (1996).

Oberea affinis Leng and Hamilton
Colchester, Debert, 11 July 1991, Georgeson, E, NSDNR
Colchester, Debert, 18 July 1991, Smith, TD, NSDNR

This species is known from Manitoba, Ontario and Quebec in Canada (McNamara 1991) and is not recorded for Atlantic Canada or northern New England in Downie & Arnett (1996). The larvae feed on *Rubus* spp. stems (Linsley & Chemsak 1995, Yanega 1996).

II. Reported in McNamara (1991) or Downie & Arnett (1996), no specimens in collections

Typocerus acuticauda Casey
This species has a wide range in eastern North America from Iowa and Manitoba east to Nova Scotia and Georgia (Linsley & Chemsak 1976, McNamara 1991). Linsley & Chemsak (1976) explicitly state the range extends to Nova Scotia and this is presumably the source of the report in McNamara (1991). They also suggest that this is a relatively rare species throughout its range. The larval host is unknown (Linsley & Chemsak 1976, 1997).

Brachyleptura vagans (Olivier)
This species has often been confused with *B. champlaini* (Linsley & Chemsak 1976, Yanega 1996). I suspect the inclusion in Downie & Arnett (1996) is because of this confusion. All specimens of *Brachyleptura* in eastern Canada that have been examined are either *B. champlaini* or *B. rubrica*. This is consistent with *B. vagans* not being included in McNamara (1991) anywhere in eastern Canada.

Semanotus ligneus ligneus (Fabricius)
McNamara (1991) reports the cedar borer from Manitoba, Ontario, Quebec and Nova Scotia in Canada. Presumably the Nova Scotia record is included on the strength of a dot on the distribution map in Linsley (1964). This record appears to be in southern Annapolis County. White Cedar, *Thuja occidentalis,* is a very rare plant in Nova Scotia, but southern Annapolis County is one of the few places where it does occur (Pronych & Wilson 1993, Roland 1998). Besides cedar, the larvae of *S. ligneus* feed in junipers and possibly other conifers (Baker 1972).

Xylotrechus quadrimaculatus *(Haldeman)*
This species is generally distributed in eastern deciduous forests from Manitoba east to New Brunswick and south into the south-central United States (Linsley 1964 Baker 1972, McNamara 1991, Yanega 1996). Larvae feed on twigs of birches, beech, and alder, all species that are common and widespread in Nova Scotia (Hosie 1990, Roland 1998).

Discussion

Many species of cerambycids from Nova Scotia were not included in the two recent compilations examined by us (McNamara 1991, Downie & Arnett 1996). The two compilations reported a total of 56 species, while 87 species were in the collections examined. It is sobering to think that we increased the number of species known in the province by about 64%. It is also sobering to think that this is for a well-known group of beetles that are frequently collected by the generalist. The situation is undoubtedly worse for groups, such as the Phalacridae, Latridiidae, Elateridae and Staphylinidae for which basic taxonomy is still being worked out.

Despite the fact that they missed many species for Nova Scotia, the two recent compilations are effective in many ways. Bousquet's (1991) 'Checklist of Beetles of Canada and Alaska' is an invaluable tool. It has compiled much distributional information. Its weakness was the incompleteness of the information available. Apparently, the list of Cerambycidae (McNamara 1991) was compiled from Linsley and Chemsak's publications (see Linsley & Chemsak 1997) and the CNCI, but without reference to the collection of the Nova Scotia Museum or any other regional collection in Nova Scotia. The number of additions we compiled demonstrates the importance of these regional collections. It is also a signal that entomologists working with these regional collections need to publish distributional studies so that the information is available for broad compilations. Useful and comprehensive distributional works depend on the cooperation and exchange of information between regional and national natural history collections.

Downie & Arnett's (1996) 'Beetles of Northeastern North America' is a noble attempt to compile identification keys for all beetles in the area. At this it is reasonably successful. Accurate distributional information would have been a useful addition to the keys. However, for Nova Scotia the distributional information is woefully inadequate, fewer than a third of the species of Cerambycidae are included.

Recognition of the Brown Spruce Long-horn Beetle created a tremendous controversy in Nova Scotia (e.g. Freedman 2001, Robertson 2001, Ricciardi 2001). An eradication program designed for spot infestations was put into place (Forestry Canada 2000), in this case a minimum of ten years after the introduction. Why did it take so long to recognize the problem? The short answer is that we did not have an accurate, basic inventory of Cerambycidae in Nova Scotia or the expertise to prepare such an inventory. Understanding wood boring beetles has not been a priority for the public, for government agencies or research institutions. With such a low priority the expertise has not been available. This lack of interest is not limited to the Cerambycidae as shown by this quote from a recent book on forest insect pests in Canada: "There is no current research being conducted in Forestry Canada on any of the wood-boring insects described in this chapter." (Safranyik & Moeck 1995). Without the expertise or the inventory it is extremely difficult to recognize and identify a new arrival and as a result the specimens of Brown Spruce Long-horned Beetles sat misidentified, as a very similar native species, in a collection for almost 10 years.

The lack of expertise and lack of basic inventories has broader implications for conservation. Introduced species are recognized as the second most important risk factor for declines in species at risk, behind habitat loss. Through transport of novel pathogens, competition with similar native congeners, predation upon relatively poorly defended native species or alteration of natural community structure, introduced species may change the environment and contribute to population declines. Quick recognition of novel introduced species may mitigate the problems. However this is only possible if we know what the native species are, and this is only possible if knowing the native fauna is valued.

Recently introduced species may be the focus of eradication or control programs, such as that against Brown Spruce Longhorns. If we do not know what native species live in a broad area such as a whole province and fulfill similar ecological functions, how can we realistically determine whether attempts to eradicate a newly introduced species will be detrimental to native species — let alone uncommon or rare native species? For example the program to eradicate the Brown Spruce Longhorn from Point Pleasant Park in Halifax undoubtedly is killing numerous native cerambycids and other xylophagous beetles. Will populations of native species be exterminated? Are these species common or rare in the province? Point Pleasant Park is the only place in Nova Scotia where *Tetropium schwarzianum* is known. If this was a frog or salamander there would be no question that conservation of a rare native species would be granted some weight in the assessment of the eradication program. Our lack of knowledge and expertise in the distribution and abundance of cerambycid beetles compromises our ability to make wise decisions about both conservation and eradication efforts – which may not be uncoupled.

In summary, we have improved the inventory of cerambycid beetles and our understanding of the beetle fauna of Nova Scotia. Local and regional collections are a valuable resource that, combined with the major national collections, can provide a more complete inventory of beetles in Nova Scotia. Both regional and national collections need to be supported so that museum workers can make their findings known to ecologists and managers who in turn can effectively plan strategies for conservation, ecological monitoring and forest management in eastern Canada.

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OBSERVATIONAL RECORD

EPILITHIC DIATOMS OF THE STREAM OUTFLOW OF WILLIAMS LAKE, HALIFAX, NOVA SCOTIA, WITH NEW RECORDS FOR THE PROVINCE

ALISON R. SHERWOOD*[1] AND RONALD J. DECKERT[2]
[1]*Department of Botany, 3190 Maile Way, University of Hawai'i,*
Honolulu, Hawai'i, U.S.A. 96822
[2]*Department of Biological Sciences, Northern Arizona University,*
Flagstaff, Arizona, U.S.A. 86011

A December 2000 sampling of epilithic diatoms from the outflow of Williams Lake, Halifax County, Nova Scotia, recorded 31 species not previously known from Nova Scotia.

Un échantillonnage effectué en décembre 2000 dans l'émissaire du lac Williams (comté de Halifax) a révélé la présence de 31 espèces de diatomées épilithiques qui n'avaient jamais été mentionnées en Nouvelle-Écosse.

Introduction

From a December 2000 sampling of epilithic diatoms from the outflow of Williams Lake (44°37'N, 63°36'W), Halifax County, Nova Scotia, the following taxa were recorded. The data are of interest due to the large number of new records (*) for the province, as determined from a checklist of freshwater diatoms reports from publications such as Blouin et al. (1984), Delorme et al. (1984), Staker & Hanic (1978) and Vaughan et al. (1982).

Epilithic diatoms identified from the stream outflow of Williams Lake

Achnanthidium minutissimum (Kütz.) Czarn.*
Actinella punctata Lewis
Aulacoseira granulata (Ehrenb.) Simonsen
Brachysira serians (Bréb. ex Kütz.) Round et D.G. Mann*
B. vitrea (Grun.) R. Ross ex B. Hartley
Cocconeis placentula var. *lineata* (Ehrenb.) Van Heurck*
Cyclotella comta (Ehrenb.) Kütz.
C. stelligera (Cleve et Grun.) Van Heurck*
Cymbella cesatii (Rabenh.) Grun. ex A.W.F. Schmidt*
Diatoma tenue var. *elongatum* Lyngb.*
Encyonema caespitosum Kütz.*
E. gracile Rabenh.*
E. silesiacum (Bleisch ex Rabenh.) D.G. Mann*
Eunotia curvata (Kütz.) Lagerst.*
E. curvata var. *capitata* (Grun.) R.M. Patrick*
E. curvata var. *subarcuata* (Naeg.) Woodhead et Tweed*
E. incisa W. Sm. ex Greg.
E. parallela Ehrenb.*

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* Author to whom correspondence should be addressed.

E. pectinalis f. *minor* (Dillwyn) Rabenh.
E. pectinalis var. *ventricosa* Grun.
E. vanheurckii var. *intermedia* (Krasske) R.M. Patrick*
Fragilaria acidobiontica Charles*
Frustulia rhomboides var. *crassinervia* (Bréb.) R. Ross*
Gomphonema acuminatum Ehrenb.*
Gomphonema sp. #1 PIRLA*
G. gracile Ehrenb. emend. Van Heurck*
G. variostriatum Camburn et Charles*
Neidium affine (Ehrenb.) Pfitz.*
Nitzschia recta Hantzsch*
Pinnularia braunii var. *amphicephala* (Mayer) Hust.*
P. latevittata Cleve*
P. mesolepta var. *angusta* Cleve*
Psammothidium marginulatum (Grun.) Bukht. et Round*
Rossithidium linearis (W. Sm.) Round et Bukht.*
Sellophora rectangularis (W. Greg.) Lange-Bert. et Metzeltin ex Lange-Bert.*
Semiorbis hemicyclus (Ehrenb.) R.M. Patrick*
Stauroneis anceps f. *linearis* (Ehrenb.) Hust.*
Surirella biseriata var. *bifrons* f. *amphioxys* (W. Sm.) Hust.*
Tabellaria flocculosa (Roth) Kütz.
T. quadriseptata Knuds.

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BEETLE DIVERSITY ASSOCIATED WITH FOREST STRUCTURE INCLUDING DEADWOOD IN SOFTWOOD AND HARDWOOD STANDS IN NOVA SCOTIA

DANIEL KEHLER, SØREN BONDRUP-NIELSEN* and CRISTINE CORKUM
Centre for Wildlife and Conservation Biology
Acadia University
Wolfville, Nova Scotia, Canada, BOP 1XO

Associations between beetles and forest stand characteristics, as well as beetle diversity, were investigated for 41 forest stands in Nova Scotia, Canada. Over 200 morphospecies from 45 Families of beetles were caught using window flight-intercept traps. In both years, correspondence analysis revealed distinct groupings of softwood and hardwood stands based on species assemblages. Multiple regression analysis was used to determine associations between forest variables and total species richness. Analyses were conducted for all stands combined and for hardwood and softwood stands separately. Hardwood stands had greater beetle richness than softwood stands. Within hardwood stands, volume of intermediate-sized deadwood was the best predictor of total species richness. Within softwood stands, volume of well-decayed deadwood was the best predictor of total beetle richness. Deadwood volume was associated with stand age in softwoods, and it appears that over 140 years is required for deadwood volume to reach pre-disturbance levels.

On a étudié des associations entre les coléoptères et les caractéristiques des peuplements ainsi que la diversité des coléoptères pour 41 peuplements de la Nouvelle-Écosse, au Canada. Plus de 200 morpho-espèces appartenant à 45 familles de coléoptères ont été capturées à l'aide de pièges-fenêtres. Pour les deux années, des analyses de correspondance ont révélé des regroupements distincts dans les peuplements de résineux et de feuillus, d'après les assemblages d'espèces. On s'est servi d'une analyse de régression multiple pour établir des associations entre des variables des forêts et la richesse totale en espèces. Des analyses ont été effectuées pour l'ensemble des1 peuplements et séparément pour les peuplements de feuillus et pour les peuplements de résineux. La richesse en coléoptères était plus grande dans les peuplements de feuillus, pour lesquels le volume de bois mort de taille moyenne constituait le meilleur indicateur de la richesse totale en espèces. En ce qui concerne les peuplements de résineux, c'était le volume de bois mort bien décomposé qui était le meilleur indicateur de la richesse totale en coléoptères. Dans le cas des résineux, le volume de bois mort était associé à l'âge du peuplement, et il semble qu'il faille plus de 140 ans pour retrouver les niveaux pré-perturbation.

Introduction

In conservation, it is important that we understand the processes and patterns in an ecosystem responsible for the generation, maintenance, and loss of biodiversity. The study of habitat associations allows one to identify key patterns correlated with species diversity by relating ecological parameters to the distribution and abundance of species. Most studies of habitat associations for vertebrates involve single species, and many give only qualitative information about habitat associations (e.g. Bias & Gutierrez 1992, Adams & Morrison 1993, Conway & Martin 1993, but see Lindenmayer et al. 1993, Pausas et al. 1995). In forest management, qualitative information on species assemblages may prove most useful in designing forestry practices that maintain biodiversity.

The importance of dead and decaying wood has been the subject of recent interest in forest management (Maser 1994). A number of authors have examined the relationship between forestry and coarse woody debris dynamics (e.g. Gore & Patterson 1986, Kirby et al. 1991, Hagan & Grove 1996), especially as it relates to older forests (Harmon & Hua 1991, Stewart & Burrows 1994, Tyrell & Crow 1994).

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* Author to whom correspondence should be addressed.

Deadwood is involved in a number of ecological processes in forests. The presence of deadwood reduces soil erosion, affects soil development, acts as a seedbed for forest plants, and plays a role in energy and nutrient flow by storing water and nutrients (Franklin et al. 1981, Harmon et al. 1986). Deadwood probably also sequester carbon, but this area has received little work to date (Harmon et al. 1990, Harmon & Hua 1991). In forested ecosystems, deadwood also provides habitat for a multitude of organisms, including fungi (Bader et al. 1995), bryophytes (Söderström & Jonson 1992), birds (Angelstam & Mikusinski 1994) and insects (Brown 1991, Siitonen 1994).

Insects have long been of interest to foresters, primarily as competitors for valuable wood resources. Due to the recent attention to biodiversity, interest in non-pest insect species living in forests has increased. Research in Scandinavia, where there is a long history of intensive forest management, has revealed the decline of hundreds of forest species as a result of forestry operations (Stokland 1991). These species are not traditional indicator or flagship species, such as birds or mammals, but rather invertebrates, fungi and spore-bearing plants. Several hundred forest invertebrates have been red-listed in Sweden, including over 500 species of beetles (Berg et al. 1994). In Sweden, old trees, logs and snags have been identified as important habitat elements for endangered invertebrates, fungi, lichens and bryophytes (Berg et al. 1994). In addition, a number of habitat associations have been documented between saproxylic insects and deadwood parameters, such as different tree species, moisture content, temperature, and nutrient status of dead and decaying wood (Ikeda 1987, Warren & Key 1991, Araya 1993).

Beetles (Order Coleoptera) are the most numerically rich taxa with over 300,000 species described (Papp 1984). Beetles serve a variety of roles in forests: as prey for other organisms, such as insectivorous birds, as predators, as pollinators, as herbivores, and as decomposers (Dillon & Dillon 1972). Relative to some invertebrate groups, beetle taxonomy is fairly well known, and previous research from Scandinavia and elsewhere has documented significant associations between beetles and different deadwood characteristics, as well as negative impacts such as species loss resulting from forestry operations (Niemelä et al. 1988, 1993, Chandler & Peck 1992, Baguette & Gerard 1993, Buse & Good 1993, Halme & Niemelä 1993, Greenberg & Thomas 1995, Michaels & McQuillan 1995).

Very little is known about the status of beetles and beetle habitat associations in the North American Northern Hardwood Forest. This knowledge is essential in designing forest management practices that are sensitive to beetle habitat requirements. This present study documents habitat associations of beetles in the Acadian forest, a subsection of the Northern Hardwood Forest (Loucks 1959). More specifically, we were interested in 1) performing a partial inventory of forest beetles, 2) determining aspects of forest structure correlated with beetle species richness, and 3) quantifying deadwood volumes in different forest types.

Methods

Sampling took place in central Nova Scotia within an area 300 km long by up to 100 km wide (Fig 1). Beetles were sampled at the level of the forest stand. Stands to be sampled were selected randomly from stands that met the following criteria: Softwood stands were greater than 70% red spruce (*Picea rubens*) and balsam fir (*Abies balsamea*); Hardwood stands were greater than 70% sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), yellow birch (*Betula alleghaniensis*) and white birch (*Betula papyrifera*). Stands had to be greater than 2.5 ha, and were greater than 300 m from

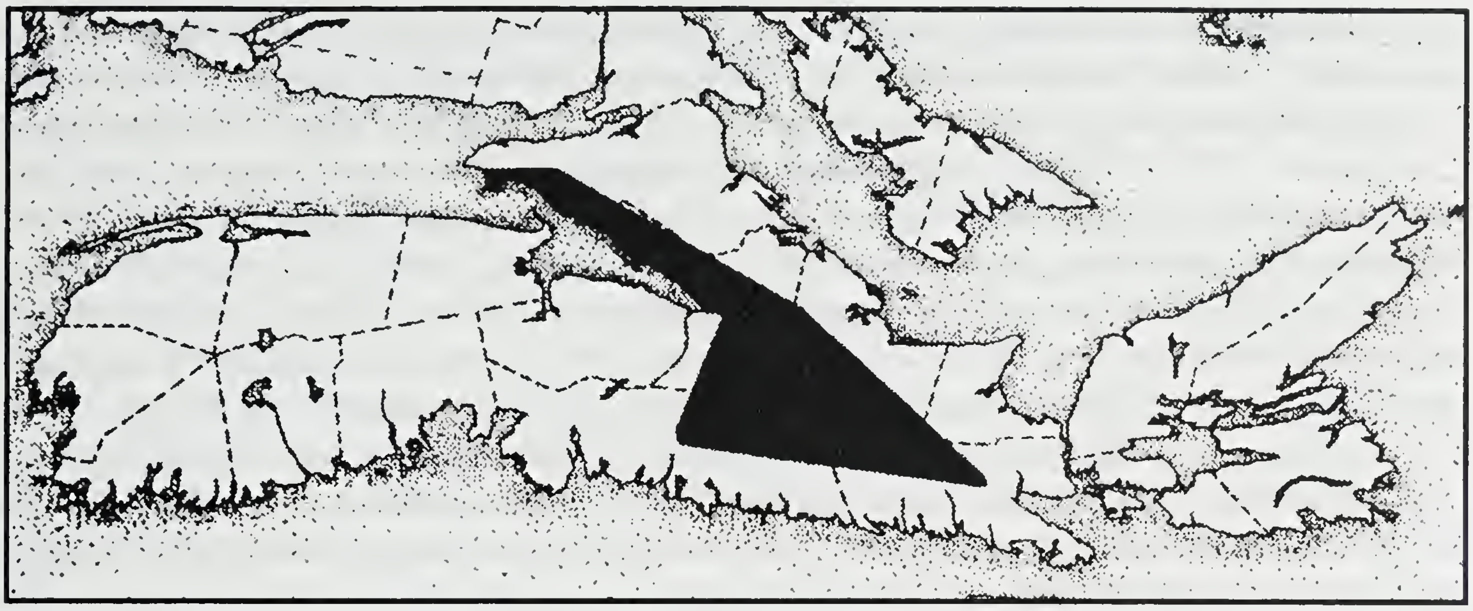

Fig 1 Map of Nova Scotia. Blackened area represents general location of sampling sites.

any road. In 1994, 11 hardwood and 10 softwood stands were sampled, and in 1995, 10 softwood and 10 hardwood stands were sampled, for a total of 41 forest stands. The window flight-intercept trap was used to sample for beetles. This trap type has been used successfully (Bakke 1975, Økland et al. 1996, Stokland 1997, Siitonen 1994, Sippola et al. 1992). This passive sampling technique is suited for catching flying Coleoptera (Marshall et al. 1994), many of which in forests are deadwood-requiring Coleoptera (Økland 1996, Stokland 1994). Of 513 beetle species caught in flight intercept traps by Økland (1996), 194 (37.8%) were known obligate deadwood associates, representing 27.7% of all deadwood associates in Norway.

Flight-intercept traps were constructed from two 30 x 30 cm pieces of transparent plastic, connected at a right angle to form two bisecting planes, with opaque plastic rain covers above and funnels below. A 50 % water/ 50 % ethylene glycol mixture was used in the collection vial under the funnel to preserve beetles that had fallen into the trap. In 1994, beetles were sampled from July 10 to August 31, using 3 traps per stand. In 1995, beetles were sampled from May 1 to July 31, using 6 traps per stand. All traps were hung at a minimum distance of 50 m from the stand edge and then every 35 m on a transect running through the middle of the stand. Traps were hung at a height of 1.5 m from existing tree branches. Traps were emptied every nine days in 1994 and every 14 days in 1995. The difference in methodology between years could affect the results but to control for this a 'year effect' was incorporated in the analyses.

The contents of each sample from the traps were rinsed and transferred to 70% ethanol. The contents were then sorted, separating the beetles from the rest of the material. The beetles from each sample were then sorted into morphospecies under a dissection microscope. One individual of each sorted group from each collection was pinned for later identification. This collection is housed at the Nova Scotia Museum of Natural History, Halifax, Nova Scotia, where identification of pinned specimens is being carried out by an insect taxonomist.

In 1994, 3 vegetation sampling points were used per stand, located at each trap. A prism sweep (BAF 1) was used to determine percent hardwood basal area (PERCHWBA), hardwood and softwood basal area (HWBA and SWBA), as well as hardwood, softwood and total tree density (HWDENS, SWDENS and TOTDENS) (Avery 1967). Two trees of mean diameter (based on trees in prism sweep) were cored at breast height using an increment bore to determine age (AGE) and the amount of deadwood was quantified by volume using a 10m x 10m quadrat centered on each trap (DWTOT). For each piece of deadwood > 5 cm at the smallest end, the length, diameter at both ends, and decompositional state was recorded. Decompositional state included three categories: STATE1 - hard: no penetration when probed by metal calipers, STATE2 - intermediate: outer soft, inner hard. Partial penetration by steel calipers, STATE3 - soft: easily penetrable throughout using steel calipers. Deadwood was also divided into 3 size classes: SIZE1 - largest diameter between 5 and 15 cm, SIZE2 - largest diameter between 15 and 30 cm, SIZE3 - largest diameter > 30 cm. Deadwood volume was calculated for each piece based on the frustrum of a cone (Harmon & Sexton 1996)

In 1995, 6 prism sweeps were conducted at a random distance up to 50 m from each trap perpendicular to the axis of the trap line. To quantify deadwood, we used ten 10m x 10m quadrats, spaced at 20 metre intervals along the trap line and at a random distance up to 50 m from each trap, perpendicular to the axis of the trap line. The location of each successive prism sweep and deadwood quadrat alternated from one side of the trap line to the other. In 1995, the largest tree in each prism sweep was cored. In both years, the ages of older hardwoods stands were not measurable using the increment bore due to blurriness of the rings and extensive heart rot. Thus no analyses using age were possible for hardwood stands.

The larger number of prism sweeps and deadwood plots were required in 1995 to adequately characterize the habitat surrounding the larger number of traps. However, only averages for all attributes per stand are used in analyses, thus greatly decreasing the chance that differences in methodology should have any consequence.

Statistical Analysis

To evaluate the flight-intercept method of trapping, we calculated a species accumulation curve for the 6 traps used in 1995. The species accumulation curve is based on the cumulative number of species added to the stand total as each additional trap is considered. To derive the curve, we randomized the trap order within stands 10 times and calculated the cumulative number of species with each additional trap for each randomization. These results were then averaged across the 20 stands.

A draw back of the flight-intercept method of catching beetles is that abundances among species cannot be compared as different species have different flight behaviours. Furthermore, only beetles with flight behaviour such that they intercept the trap are caught. For example, if traps are hung at one metre above the ground, beetles that fly above or below that height will not be caught. Thus, catching only one specimen of a particular species does not signify that it is rare. It is only rare with respect to the particular trapping method. Therefore, it is important to keep in mind that a beetle sample from a flight-intercept trap only represents a subsample of species of beetles. Thus only presence/absence of species should be analysed. Therefore, the variable 'total species richness' is used as the response variable in this study.

As beetles caught differed with respect to many ecological and physiological characteristics, it is unlikely that any single trap type will sample all species equally. Thus, we did not use information about abundance when comparing among species, but focused on presence/absence and species richness.

Correspondence analysis (ter Braak 1994), an ordination technique, was used to groups stands according to beetle species composition. Correspondence analysis is based on species showing a unimodal response of abundance to an environmental gradient (ter Braak 1994). This assumes that for every species and every environmental variable, there is an optimal range where that species is best adapted. Stand scores are calculated in such a way that stands that lie in close proximity on the ordination biplot are similar in species composition, and distant stands are dissimilar in species composition. Correspondence analysis was performed, based on species incidence data, for each year separately using CANOCO (ter Braak 1988).

Multiple linear regression analysis was used to relate total species richness to the forest structure variables. Analyses were conducted for all stands together and for hardwood and softwood stands separately. For each response variable, a forward stepwise procedure was used. The criterion for exit and entry of variables was set at $p = 0.05$. Residuals were plotted against fitted values to check for heteroscedasticity, quantile-quantile plots were used to assess normality of the residuals, and Cook's distance plots were used to check for influential observations. To account for the differences in sampling intensity and period between years, the binary variable YEAR was first included in each model. Unfortunately, the variable YEAR will not only be a function of differences in methodology between years but also differences in weather and random variation between years. Partial R^2 values were calculated based on the variance remaining after including YEAR in the model. All linear and generalized linear models were performed using S-PLUS (Mathsoft 1995).

Results

A total of 17,358 individual beetles were caught, representing over 200 morphospecies, from 46 Families (Appendix 1). Some specimens were sent to Agriculture and AgriFood Biosystematic Research Centre, Ottawa, Canada for identification. Of these two were undescribed species.

The daily capture rate per trap was 1.23 (Table 1). The cumulative number of species caught showed a continuous increase up to 6 traps (Fig 2) and the majority of species were caught in only one trap. Thus, increasing the number of traps appears to increase the likelihood of catching species that are rare or less likely to be caught in this trap type. In both sampling years, correspondence analyses revealed a clustering of hardwood and softwood stands (Fig 3) indicating a consistent difference between the beetle species composition of hardwood and softwood stands. The separation between stand types seemed to be more evident in 1995 where softwoods also showed more variation in species composition than hardwoods.

Table 1 Overview of trapping results. Results are given for each year separately and for both years together.

	1994	1995	Total
Beetles Caught	3591	13767	17358
Trap Days	4284	9840	14134
Beetles/ Trap Day	0.838	1.40	1.23
Identified Families	34	42	46

The results of multiple regression analyses revealed the importance of percent hardwood basal area in explaining total beetle species richness (Table 2). Moreover, for total species richness only one explanatory variable (SIZE2) entered the model. Hardwood stands proved to have a higher species richness than softwood stands. However, when hardwood and softwood stands are considered separately beetle

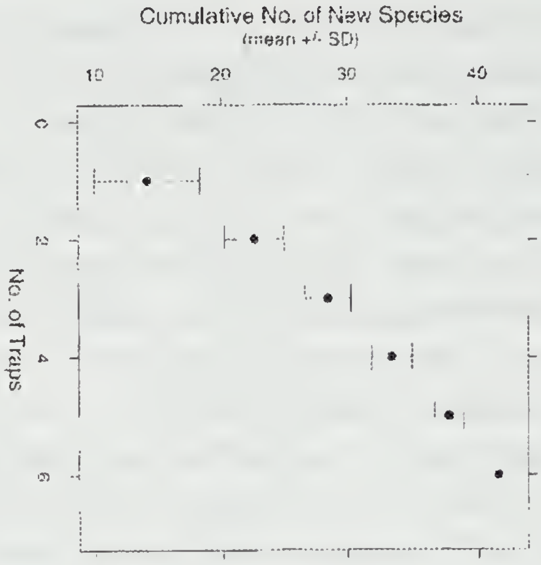

Fig 2 Species accumulation curve for 1995, based on 10 randomizations of trap order in each stand, and averaged across all 20 stands.

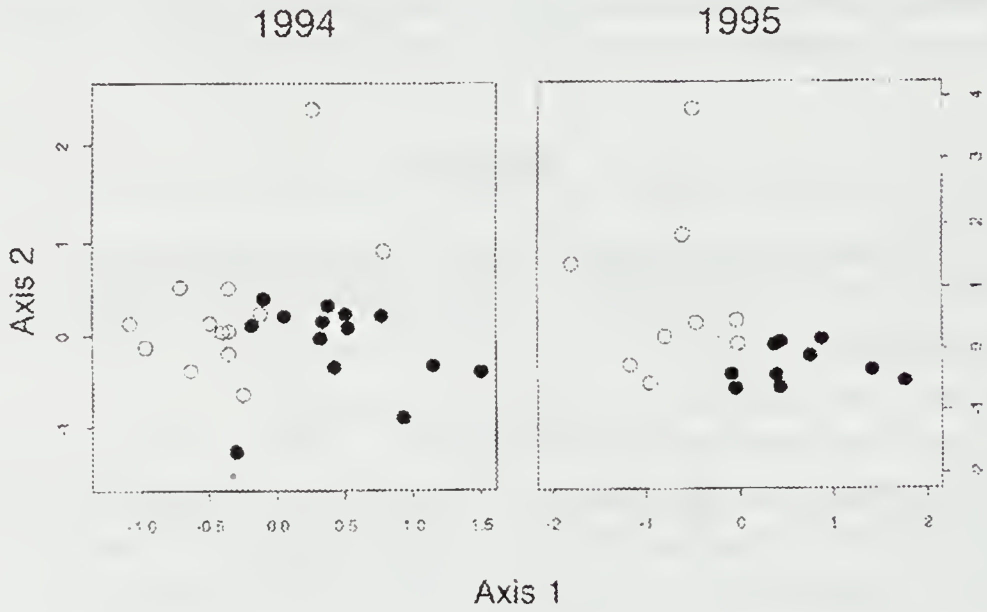

Fig 3 Results of correspondence analysis. Stands locations are plotted on species-space based on their values from the first two axes of the correspondence analysis. Open circles represent hardwood stands and filled circles represent softwood stands. Results from 1994 and 1995 are presented separately.

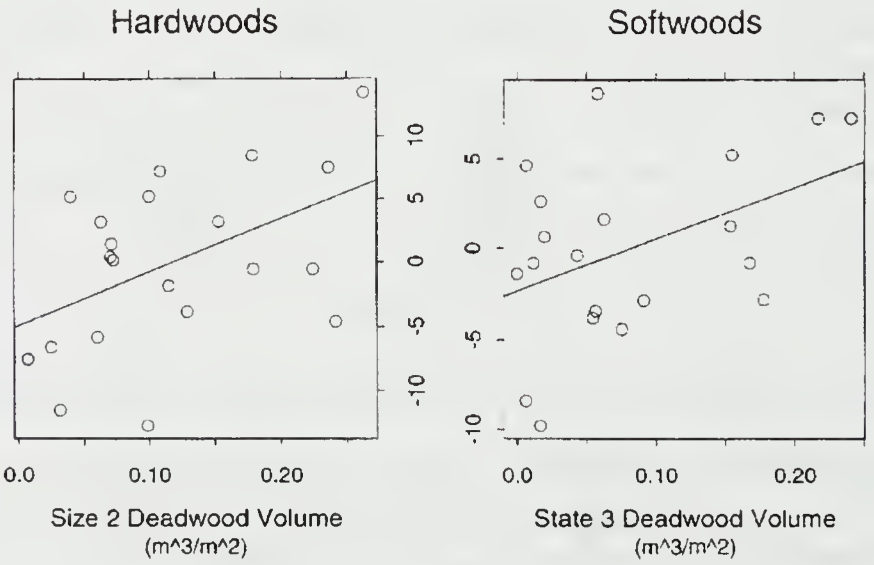

Fig 4 Relationship between SIZE2 deadwood volume and total richness in hardwood stands, and STATE3 deadwood volume and total richness in softwood stands. To control for the effect of YEAR, deadwood volumes are plotted against the residuals of a model where total richness is regressed against YEAR.

species richness is best predicted by deadwood variables (Table 3). For hardwood stands, intermediate-sized deadwood (SIZE2) proved to be the best predictor for total species richness (Fig 4). For softwood stands, well-decayed deadwood (STATE3) proved to be the best predictor of total species richness (Figure 4).

Table 2 Results of multiple regression on total species richness and species richness of each associate group for all stands. Independent variables for each model are presented by order of entry. R^2 values are given for each independent variable and for independent variables once the effect of year is removed ($R^{2}*$). Significance (p-value) was assessed using F tests. All relationships are positive.

Response	Predictor	p-value	R^2	$R^{2}*$
Total Richness	Year	0.0000	0.74	
	Perchwba	0.0000	0.12	0.46
	Size2	0.0110	0.02	0.09

Table 3 Results of multiple regression on total species richness and species richness of each associate group for hardwood and softwood stands separately. Independent variables for each model are presented by order of entry. R^2 values are given for each independent variable and for independent variables once the effect of year is removed ($R^{2}*$). Significance (p-value) was assessed using F tests. All relationships are positive except where noted by (-ve).

	HARDWOOD STANDS				SOFTWOOD STANDS			
	Predictor	p-value	R^2	$R^{2}*$	Predictor	p-value	R^2	$R^{2}*$
Total Richness	Year	0.000	0.85		Year	0.000	0.84	
	Size2	0.013	0.03	0.25	State3	0.012	0.05	0.32
	State2	0.023	0.02	0.20 (-ve)				

In softwood stands, where estimates of stand age were available, we examined relationships between all deadwood variables and stand age, while controlling for YEAR (Table 4). Only total volume, large-sized (SIZE3), and well-decayed (STATE3) deadwood volumes increased linearly with stand age. Figure 4 displays the relationship with STATE3 deadwood volume, which was also the best predictor of total species richness in softwood stands. Table 5 reports the mean deadwood volume for each deadwood size class and decompositional state, in softwoods and hardwoods. Volumes were similar between stand types, with the exception of SIZE1 deadwood volume, which was greater in softwood stands (Table 5).

Table 4 Results of simple linear regressions between stand age and deadwood variables in softwood stands, controlling for YEAR. $R^{2}*$ values are for the coefficient of determination after the effect of YEAR has been removed. Significance (p-value) was assessed using F tests and significant results are bolded.

Variable	$R^{2}*$	p-value
Size1	0.06	0.057
Size2	0.33	0.29
Size3	0.15	**0.010**
State1	0.15	0.10
State2	0.15	0.10
State3	0.31	**0.014**
Dwtot	0.27	**0.020**

Table 5 A comparison of deadwood volumes in different decompositional states and size classes between hardwood and softwood stands. Results presented are from a t-test (two-tailed, n=20).

	Softwoods	Hardwoods	T	P-value
Size1	0.10 ± 0.050	0.074 ± 0.037	2.21	**0.032**
Size2	0.15 ± 0.13	0.12 ± 0.077	0.96	0.35
Size3	0.054 ± 0.10	0.071 ± 0.074	0.64	0.52
State1	0.13 ± 0.10	0.09 ± 0.048	1.68	0.1
State2	0.094 ± 0.087	0.11 ± 0.077	0.57	0.57
State3	0.082 ± 0.076	0.065 ± 0.042	0.89	0.37
Dwtot	0.31 ± 0.22	0.26 ± 0.1	0.94	0.35

Discussion

In this study, the use of the flight-intercept trap proved useful in the rapid generation of a biologically meaningful data set. However, it is important to keep in mind that, because of the limitations of the sampling methodology, the beetles species caught only represent a subsample of the total number of beetle species found in our study area. However, we found a higher beetle species richness in hardwood stands than in softwood stands. The method also allowed us to detect distinct differences in the beetle community composition of hardwoods and softwoods in both years of the study. Within softwood and hardwood stands, stands with high volumes of larger, well-decayed deadwood had higher species richness. Several deadwood variables were positively related to age in the softwood stands tested, and stands with high deadwood volumes were particularly favourable for many of the common species analyzed.

The daily capture rates per trap (1.23 beetles/ trap) were similar to those found in Finland of 1.16 (Sippola et al. 1995), but higher than those reported from Norway of 0.25 (Økland 1996) and 0.5 (Økland et al. 1996).

The species accumulation curve would suggest caution in the use of the flight-intercept trap. The trap tends to catch very few individuals of any one species, and in excess of 6 traps per stand is required in order to sample the majority of species susceptible to capture. In fact, observations (Bondrup-Nielsen 1996), suggest that the species accumulation curve does not asymptote even when using 40 traps per stand. These problems, however, may not be unique to the flight-intercept trap. Oliver and Beattie (1996a) report a very similar curve using 5 groups of 2 pitfall traps for beetles. The problem is less acute for ants and spiders, and may be a consequence of the higher diversity of beetles relative to other taxa. However, the results of the correspondence analysis also suggest that despite potential problems with the trap, trap catches were sensitive enough to allow hardwood stands and softwood stands to separate out on the basis of the beetle community, even with the use of only 3 traps per stand.

It is important to consider that although a large number of species were sampled in this study, these species likely represent only a fraction of the actual beetle species richness in Nova Scotian forests. A variety of different trap types would be required to more effectively sample the forest beetle community (Marshall et al. 1994). The partial inventory of this study although based on morphospecies with voucher specimens kept in the Department of Biology Museum, Acadia University, represents benchmark data on the presence, distribution, and natural history of beetles in Nova Scotia, and as such, vital information for future monitoring efforts (Haila & Margules 1996).

The importance of stands with high volumes of larger, well-decayed deadwood was evident. The sampling method precludes any inference about the role of deadwood in structuring beetle communities, as there is no evidence that beetles caught in traps also used deadwood as habitat. Evidence for a relationship between deadwood volume and beetle richness from other studies using the flight-intercept trap is mixed. Økland (1996) determined that to achieve a coefficient of determination (R^2) above 0.1 between saproxylic beetle species richness and deadwood density required assimilating information over at least a 32 ha area. However, Sippola et al. (1992) did find a positive relationship between deadwood volume and richness of saproxylic beetles, using a sampling grain size of 1 ha. It is curious to note that in both hardwood and softwood stands, total species richness showed the same trend with deadwood volume. This may be due to increased deadwood-dependent fungal substrates, or because high deadwood is an indicator of high stand structural diversity. A number of studies have noted the importance of increased structural diversity to species diversity (e.g. Hansen et al. 1991, Freedman et al. 1994, Mason & Quine 1995, Sippola et al. 1992), and attention to structural diversity is also a core concept of "new forestry" (Franklin 1989, Gillis 1990).

The influence of forest management on organisms has been described for a variety of taxa (see Heliovaara & Vaisanen 1984, Freedman et al. 1994 for reviews). Of concern here is the decrease in deadwood in managed forests, relative to unmanaged forests (Hansen et al. 1991, Kirby et al. 1991), likely resulting from commercial thinning and short rotation ages. Several studies have reported a positive relationship between deadwood volume and stand age (Bormann & Likens 1979, Bingham & Sawyer 1988, Gore & Patterson 1985, Kirby et al. 1991, Tyrell & Crow 1994). In this study, we also saw an increase in deadwood volume with age in softwood stands, particularly large, well-decayed deadwood. The increase was linear across the range of ages sampled (40-140 years), suggesting that greater than 140 years is required for deadwood volume to stabilize following a disturbance. As the rotation age of most softwood forestry practices in Nova Scotia is considerably less than 140 years, and beetle richness increases with deadwood, there is potential for a strong negative impact of forestry on forest beetle species. In addition, any conversion of mixed-wood and hardwood forests to pure softwood stands will also diminish species richness in these stands, as hardwood stands showed a richer beetle community for almost all species groups. Forest managers also need to consider the implication of differing species composition between stand types for regional species diversity (Noss 1983).

Several authors have suggested that one way to simplify the arduous task of quantifying biodiversity is through the use of surrogate taxa, whose richness or abundance is correlated with the richness of other taxa (Brown 1991, Kremen 1992, Warren & Key 1991, Oliver & Beattie 1996b). Thus, ideally, biodiversity assessment and monitoring efforts need involve only a few species, reducing time and energy required. Forest stand variables are easier to quantify than species abundance, as they can be measured at the researcher's leisure, and require less expertise. We suggest that forest stand variables may prove more useful as indicators of beetle species richness, as has been clearly demonstrated for bird species richness (for brief review, see Noss 1983). The usefulness of this approach stems from the well known correlation between species diversity and habitat diversity (Murdoch et al. 1972).

Although deadwood represents an economic loss to the forest industry, deadwood also represents important habitat for beetles and other organisms. The difficulty lies in determining how much deadwood is required in forest ecosystems. Only more detailed information on the role of deadwood in structuring communities will resolve this challenge.

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Appendix 1 List of Families of beetle (order Coleoptera) with number of potential species caught during this study.

Family	# of Potential Species	Family	# of Potential Species
Alleculidae	1	Hydrophilidae	1
Anobiidae	3	Lampyridae	2
Buprestidae	1	Leiodidae	3
Byturidae	1	Leptodiridae	1
Cantharidae	6	Lucanidae	2
Carabidae	5	Lycidae	3
Cephaloidae	1	Lymexyloidea	1
Cerambycidae	20	Melandryidae	7
Cerylonidae	2	Melyridae	1
Chrysomelidae	8	Mordellidae	2
Ciidae	1	Nitidulidae	12
Cleridae	3	Oedomeridae	1
Coccinellidae	5	Pyrochroidae	1
Corylophidae	1	Pythidae	1
Cucujidae	1	Rhizophagidae	1
Curculionidae	9	Scarabaeidae	8
Dermestidae	1	Scirtidae	3
Dytiscidae	1	Scolytidae	14
Elateridae	27	Silphidae	5
Endomychidae	1	Staphylinidae	21
Eucnemidae	1	Tenebrionidae	6
Erotylidae	2	Tetratomidae	1
Histeridae	1	Throscidae	1

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CHANGES IN POPULATIONS OF NESTING SEABIRDS ON THE BIRD ISLANDS, CAPE BRETON, NOVA SCOTIA

DAVID B. McCORQUODALE[1*], DAN B. BANKS[2], MATTHEW I. KERR[1],
RICHARD W. KNAPTON[1], and DAVID L. HARRIS[3]
[1]Department of Behavioural and Life Sciences,
University College of Cape Breton,
Box 5300, Sydney, Nova Scotia B1P 6L2
[2]Department of Natural Resources,
PO Box 610, Baddeck, Nova Scotia B0E 1B0
[3]Department of Natural Resources
300 Mountain Rd., Coxheath, Nova Scotia B1L 1A9

The Bird Islands support the largest colonies of nesting seabirds in Nova Scotia. From a continental perspective the islands host one of the largest Great Cormorant (*Phalacrocorax carbo*) colonies in North America and a significant Razorbill (*Alca torda*) colony. However the islands are best known for nesting Atlantic Puffins (*Fratercula arctica*). Populations of all species have changed over the past 75 years, none so dramatically as Black-legged Kittiwakes (*Rissa tridactyla*). Kittiwakes colonized the islands 20 years ago and are now the most numerous nesting seabirds. Two other recent colonists, Herring (*Larus argentatus*) and Great Black-backed Gulls (*L. marinus*) are the next most common nesting species on the islands. In contrast the small colony of Common Murres (*Uria aalge*) and the large colonies of Arctic (*Sterna paradisaea*) and Common Terns (*S. hirundo*) of the 1920s have disappeared. Here we present recent estimates of breeding populations and summarize the data on changes in populations in the past 75 years based on a review of the literature, and surveys conducted from boats circumnavigating the islands during 11 different years from 1976 until 2000. The changes in breeding populations of seabirds on the Bird Islands show that their importance for conservation has changed through the years. For example in the 1920s about one third of all nesting Double-crested Cormorants in Nova Scotia were on the Bird Islands. In 1933 no Great Cormorants nested on the islands. In contrast in 2000 they supported the largest colony of Great Cormorants in North America and less than 1% of the Double-crested Cormorants in eastern Canada.

En Nouvelle-Écosse, ce sont les îles Bird qui abritent les plus grosses colonies d'oiseaux de mer nicheurs. Les îles hébergent une des plus grosses colonies de Grands Cormorans (*Phalacrocorax carbo*) de l'Amérique du Nord et une colonie importante de Petits Pingouins (*Alca torda*). Cependant, les îles sont plus connues pour les Macareux moines (*Fratercula arctica*). Depuis les 75 dernières années, les populations de toutes les espèces ont changé, mais c'est la population de Mouettes tridactyles (*Rissa tridactyla*) qui a changé le plus. Il y a vingt ans, ces mouettes ont colonisé les îles et sont devenues les oiseaux de mer les plus abondants à s'y reproduire. Deux autres espèces ayant colonisé les îles depuis peu, le Goéland argenté (*Larus argentatus*) et le Goéland marin (*L. marinus*), arrivent au second rang pour ce qui est des oiseaux nicheurs les plus nombreux sur les îles. Par contre, la petite colonie de Guillemots marmettes (*Uria aalge*) et les grosses colonies de Sternes arctiques (*Sterna paradisaea*) et de Sternes pierregarins (*S. hirundo*) qui y vivaient durant les années 1920 ont disparu. Nous présentons ici des évaluations récentes des populations d'oiseaux nicheurs et les tendances démographiques depuis les 75 dernières années à partir d'une revue de la documentation, ainsi que les résultats de relevés effectués dans 11 années, entre 1976 et 2000, à bord de bateaux qui ont fait le tour des îles. Les changements dans les populations d'oiseaux de mer qui se reproduisent sur les îles Bird montrent que leur importance sur le plan de la conservation a varié au cours des années. Par exemple, dans les années 1920, environ un tiers de tous les Cormorans à aigrettes qui nichaient en Nouvelle-Écosse le faisaient sur les îles Bird. En 1933, aucun Grand Cormoran ne nichait sur les îles, tandis qu'en 2000, elles abritaient la plus grosse colonie de cette espèce en Amérique du Nord et moins de 1 % des Cormorans à aigrettes de l'est du Canada.

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[*] Author to whom correspondence should be addressed.

Introduction

The Bird Islands support the largest and most significant seabird nesting colonies in Nova Scotia (Brown et al. 1975, Tufts 1986, Erskine 1992). Holland recognized the importance of the islands for nesting seabirds in 1766 (Harvey 1935). Unfortunately his writings do not document which species or how many were nesting. Bayley (1925) compiled the first reasonably complete survey of nesting seabirds. He visited the islands several times in the early 1920s and presented a summary of his sightings and counts. Since then some species have disappeared (e.g Arctic Tern), others have colonized the islands (e.g. Black-legged Kittiwake) and the populations of all have fluctuated.

The Important Bird Area (IBA) program aims to establish "a network of sites that conserve the natural diversity of Canadian bird species and are critical to the long-term viability of naturally occurring bird populations" (Dietz & Chiasson 2000). Supporting a minimum of 1% of the continental population makes a site worthy of consideration by the IBA program. The combination of close to 10% of the continental population of Great Cormorants and the significant, on a provincial scale, populations of other nesting seabirds (e.g. Atlantic Puffin, Razorbill, Black-legged Kittiwake), made the Bird Islands an obvious choice for selection as one of the first IBA sites in Nova Scotia in 1999 (Dietz & Chiasson 2000).

Besides Great Cormorants, other species that nest on the islands have been the cause for conservation concern historically. For example, fewer than 70 pairs of Double-crested Cormorants nested in Nova Scotia in the 1920s, including about 25 on the Bird Islands (Lewis 1928). Through the 1970s this species was the subject of concern because of low populations in eastern North America (Hatch 1995, Weseloh et al. 1995). However, in the past two decades concern has switched to the conflicts between people and rapidly expanding populations (Milton & Austin-Smith 1983, Hatch 1995, Milton et al. 1995). Similarly, Razorbill populations in North America were severely reduced by egg harvesting and hunting in the 1800s (Nettleship & Evans 1985). After a limited recovery, further declines were noted in the Gulf of St Lawrence between the 1960s and 1980s (Nettleship & Evans 1985, Chapdelaine et al. 1999). More recently, there have been increases at several colonies in the Gulf of St. Lawrence (Chapdelaine et al. 1999).

Fluctuating populations, new immigrants and local extirpations change conservation priorities and suggest the value of monitoring nesting populations on the Bird Islands. Here we bring together published population estimates and counts of nesting seabirds on from the past 75 years. We also provide results from our surveys in the past 25 years. These data document local extirpations, colonization and population trends. We also compare population changes on the Bird Islands with patterns elsewhere in eastern Canada.

Study Site

The Islands The two Bird Islands are at the eastern edge of St. Anns Bay, offshore from Cape Dauphin, Cape Breton Island, Nova Scotia (46° 22' North, 60° 23' West). About 3 km from shore is Hertford Island (hereafter Hertford), the smaller of the two (15 ha, about 1.3 km by 125m). Less than a km to the east is Ciboux Island (hereafter Ciboux) (23 ha, about 1.6 km by 150 m). The topography and vegetation of both islands are similar. The shoreline is either steep cliffs, up to 35 m high, or a jumble of boulders and rocks that have fallen from the cliffs. Cliffs are steepest on the northwest sides of both islands. This is a result of the tilt of the underlying coarse conglomerates and sandstones from the Carboniferous (Mississipian) (Roland 1982). The flat-tops are covered with grasses (e.g. *Festuca rubra, Deschampsia flexuosa,* and *Poa pratensis*) and prostrate shrubs (e.g. *Empetrum nigrum, Potentilla tridentata* and *Juniperus communis*) (Smith & Schofield 1959). Holland claimed the islands were barren rock (Harvey 1935) which conflicts with both local oral history which suggests there were trees on the islands and Bayley's (1925) observation of stunted trees and standing dead trees. There are no trees on the islands now.

People resided at the lighthouse on Ciboux until 1952. Sheep grazing continued on the islands during the summer for many years after that. Ciboux was bought by the Nova Scotia Bird Society from Victoria County in 1958. Since 1994 it has been under the control of the Sanctuary and Scholarship Trust of that society. The province of Nova Scotia purchased Hertford in 1974 from the former lighthouse keeper, Daniel J. Campbell. For the past few decades only the occasional bird counter or boater has landed on the island. Tour boats have circumnavigated the islands daily in the summer for the past 30 years.

Methods

Estimates of populations of nesting seabirds Three methods were used to estimate populations. First, literature on seabirds on the Bird Islands was reviewed. Sources included private individuals with an interest in and knowledge of the islands (e.g. Bayley 1925), notes in regional works on birds (e.g. Lewis 1941, Tufts 1962, 1986, Erskine 1992) and censuses by the Canadian Wildlife Service (e.g. Lock & Ross 1973, Erskine 1972, Brown et al. 1975, Lock et al. 1994). Some of these are reasonably complete censuses while others focus on only one or two species. Some sources conflict directly with others. We have included all the counts and estimates that we deem to be reliable, using consistency with other surveys of about the same vintage as a primary arbiter. An annotated list of all sources consulted is available from DBM.

The second method was a survey of seabirds conducted and organized by DBB and DLH, NSDNR. A preliminary cruise was done in 1976 and then 12 surveys from 1979 to 1997. One morning in June or early July (range of dates 4 June to 8 July) four to eight people would embark in a small aluminum boat with outboard motor and circumnavigate the islands. During the trip individuals counted either nests or individuals of one or two species and all counts were recorded for each side of the two islands as the boat cruised slowly around the islands. Cormorant and kittiwake nests were relatively easy to count. The two species of cormorants were distinguished most years but for two years only cormorant spp. were counted. These have been assigned to species based on location of known colonies of the two species. Puffin and Razorbill nests are generally hidden from view. Most counts of these species are of adults standing in front of presumed nests, or adults entering or leaving nests. These counts are useful for monitoring population trends, but always underestimate total population. Black Guillemot nests are not visible and therefore all counts are of individuals. Counts were done before young were out of the nest, so counts are of adults only. Landings were made on the islands, especially Ciboux, in the late 1970s and 1988 to check for nesting Leach's Storm-petrels.

The third method involved 13 surveys from 27th May 2000 until 31st July 2000 by MIK, with assistance on some from RWK and DBM. Twelve were conducted from the deck of a tour boat operated by Captain Vincent Van Schaik of Bird Island Tours. Both nests and individuals were counted for cormorants, kittiwakes, puffins and Razorbills. Only individual guillemots were counted. Cormorant and kittiwake colonies were photographed from the boat and during a helicopter flight over the islands 31 July 2000.

Counts of nests from the photographs were co-ordinated with counts from the boat. On 31st July 2000 a ground check of Ciboux for nesting storm-petrels was also completed. Totals for each species for 2000 are reported as the highest count obtained during one day.

Species Accounts, Population Estimates and Trends

Great Cormorant (Phalacrocorax carbo) About 500 pairs of Great Cormorants nested on the islands from the early 1980s until 2000 (Table 1). There is a slight peak, approaching 600 nests, from the early 1980s until the mid-1990s. This contrasts with only 100 nests in 1925 and even lower numbers, fewer than 50 and even none in some years, through the 1930s and 1940s. Significant population growth appears to have occurred through the 1960s as shown by Neilly's count of 700 individuals in 1968 (Erskine 1972).

Table 1 Estimates of the numbers of Great Cormorant, Double-crested Cormorant and Black-legged Kittiwake during the breeding season on the Bird Islands, Nova Scotia, 1925 to 2000. The number is the number of nests, except those in parentheses which are number of individuals. No entry indicates the species was not mentioned or counted that year. A zero indicates a specific acknowledgement that the species did not nest or was not present.

Year	Great Cormorant	Double-crested Cormorant	Black-legged Kittiwake	Source
1925	100	25	0	Bayley 1925
1929	75			Erskine 1972
1933	0			Tufts 1962
1935	50+			Erskine 1972
1940	39			Tufts 1962
1962		some		Tufts 1986
1963	(200)	0		Erskine 1972
1965	(200+)	0		Erskine 1972
1968	(700)	0		Erskine 1972
1971	398	0		Lock & Ross 1973
1976			0	this study
1979	(675)		0	this study
1980	(756)		126	this study
1981	(1197)	(258)		this study*
1982	572	(110)	268	this study
1983	537	230	232	NS Colonial Seabird Database
1984	(776)	(156)	228	this study
1985			208	MacDonald 1985
1988	(541)	(186)	282	this study
1989			375	this study
1990			773	this study
1991	543	219	623	this study
1993	537	224	1456	this study*
1995	614	328	666	this study
1997	415	285	1139	this study
2000	410	245	1269	this study

* Cormorants were counted as cormorant sp. and assigned to species by location of known colonies.

Historically, the Bird Islands have been an important refuge in times of low populations and consistently one of the major colonies in North America. Population change has mirrored growth throughout Atlantic Canada and Saint Pierre et Miquelon. Early in the 20th century Bent (1922) suggested the Great Cormorant had been extirpated from North America. Although he was undoubtedly wrong, his assertion demonstrates their rarity in North America. In 1925 the Bird Islands supported the largest colony of Great Cormorants in North America, probably more than 75% of the total population (Bayley 1925, Erskine 1972). Small numbers were known from only two other locations, the North Shore of the St. Lawrence and the Magdalen Islands, Quebec (Erskine 1972). In 1940 Lewis (1941) undertook a complete survey of colonies in Canada. The 39 pairs on the Bird Islands represented 3.6% of the North American population at that time, the majority nesting on Anticosti Island and the North Shore of the St. Lawrence in Quebec. The next reasonably complete count for Canada is from the early 1970s (Lock & Ross 1973, Brown et al. 1975). The 398 nests on the Bird Islands then represented close to 15% of the total for North America. Since then, numbers on Bird Islands have been relatively stable, while the North American population has increased. Now the colonies on the Bird Islands probably represent no more than 8% of the North American population of about 5,000 pairs (Erskine 1992, Fradette 1992, Lock et al. 1994).

Double-crested Cormorant (Phalacrocorax auritus) From the early 1990s until 2000 more than 200 pairs of Double-crested Cormorants nested on the Bird Islands (Table 1), with a peak of more than 300 pairs in 1995. The largest colonies are on Ciboux and have been since they recolonized the islands in the 1970s. In the 1920s about 25 pairs nested (Bayley 1925) and Tufts (1962) reported their presence in 1940. In the 1960s and early 1970s this species was largely absent from the islands, although Tufts (1986) did find some in 1962. Since then there has been a dramatic increase, although there is some evidence of a small decrease in recent years. It is likely that estimates from the 1980s and early 1990s are low because two colonies are not visible from a boat and therefore missed by the NSDNR surveys that did not land on Ciboux.

The pattern of population change on the Bird Islands fits the general pattern observed in eastern North America over the past 75 years. Populations were low prior to 1950 and through the 1970s they appeared on lists of species of concern (Hatch 1995). Since the late 1970s there has been a dramatic increase (Chapdelaine & Bedard 1995, Hatch 1995). One exception is the complete lack of birds in the 1960s and early 1970s on the Bird Islands. Several surveys in the 1960s and 1970s explicitly state no nests of this species were present (Erskine 1972, Brown et al. 1975).

In the 1920s one of only two colonies of Double-crested Cormorants in Nova Scotia was on the Bird Islands (Lewis 1928), obviously an important refuge for a distinctly rare species in the province at that time. Since then the relative importance of the Bird Islands in the province has declined, even though the number of nests has increased. This is largely because of the burgeoning Nova Scotia population, more than 15,000 in the 1990s (Erskine 1992, Milton et al. 1995).

Several mixed colonies, of Great and Double-crested Cormorants, occur in Prince Edward Island and Nova Scotia (Lock & Ross 1973, Godfrey 1986, Milton & Austin-Smith 1983). Although the Bird Islands as a whole are a mixed colony, each sub-colony was usually either one species or the other. Since there are no trees on the islands, all nests of Double-crested Cormorants were on the ground. Ross (1974-76) found that although Double-crested Cormorants prefer to nest in trees, they use a range of nesting locations.

Leach's Storm-petrel (Oceanodroma leucorhoa) No burrows or odours of nesting petrels were found during a visit to Ciboux in July 2000. In the late 1970s and again in 1988 a few (<5) nests were found on Ciboux, mostly around old foundations of buildings. Bayley (1925) reported many petrels nesting on the Bird Islands in the early 1920s. These hole-nesting nocturnal seabirds are not easily counted. Therefore only anecdotal observations are available for the islands. They prefer to burrow amongst tree roots. As there are no trees on the islands now, nesting habitat is limited.

Herring Gull (Larus argentatus) More than 400 adult Herring Gulls were counted on the islands in June 2000. This is down from the peak counts of about 600 nests in 1971, several hundred nests in 1979 and more than 1,000 individuals in 1985. Gulls were not the focus of the NSDNR surveys and therefore the data are limited. Herring Gulls have nested on the islands since at least 1954 when Smith & Schofield (1959) estimated at least 300 young on Hertford alone. There are no nesting records prior to 1954 and Bayley (1925) explicitly stated they were casual summer visitors and did not nest.

Population trends on the islands are similar to trends for Nova Scotia and for northeastern North America. Populations were low in the early 1900s and then a tremendous population explosion (Lock 1989, Erskine 1992). In the past 10 to 15 years numbers have started to stabilize or decline. In Cape Breton this recent population decline is probably due to closure of fish plants and declining use of open landfills in the 1990s.

Great Black-backed Gull (Larus marinus) In 2000, 641 adult Great Black-backed Gulls were counted on the islands. Data for the 1980s and 1990s are lacking. Two counts, a conservative estimate of more than 600 pairs in 1979 and 750 pairs in 1971 (Brown et al. 1975), suggest a higher population through the 1970s. No other estimates are available. The 1971 count represents the first report of nesting on the islands. Godfrey (1958) considered them a common nesting species on Cape Breton Island suggesting they have nested on the Bird Islands since at least the 1950s. However he appears not to have visited the Bird Islands.

Like those of Herring Gulls, Great Black-backed Gull populations have increased dramatically in Nova Scotia and in northeastern North America through most of the 1900s (Erskine 1992). Increases in nesting on the Bird Islands have been part of this larger picture.

Black-legged Kittiwake (Rissa tridactyla) Kittiwakes were the most numerous nesting seabird on the islands in 2000, with more than 1400 nests (Table 1). The islands were first colonized in 1980 when more than 120 pairs nested. Adults were around the islands the year before but did not nest. Through the 1980s, 200-300 pairs nested each year. Then in the late 1980s the population increased again. From 1990 until 2000, there was an average of almost 1000 nests on six surveys.

The colonization and population increase on the islands is part of a general trend in Nova Scotia (Lock 1987, Erskine 1992) and the southern edge of this species range in eastern Canada (Chapdelaine & Brousseau 1989, Fradette 1992). The first nests for the province were found on the east coast of Cape Breton in 1971 and since then they have colonized seaside cliffs elsewhere in eastern Cape Breton.

Arctic Tern (Sterna paradisaea) and Common Tern (Sterna hirundo) Both Arctic and Common Terns, nested in the hundreds on the small rocks between the two islands in the 1920s (Bayley 1925). Since then there are no reports of nests. In the summer individuals fish around the islands.

Both species commonly nest around Cape Breton Island. Tern populations have declined during the past 100 years in Nova Scotia and the presence of gulls at nesting colonies is thought to be a major factor in the decline (Lock 1989, Erskine 1992). Tern colonies are ephemeral along the coast of Cape Breton. Often terns will use a location for a few years and then move to another. Because of their mobility, a broad survey of the Cape Breton coast is the only effective way to monitor population trends (Lock 1989).

Atlantic Puffin (Fratercula arctica) The more than 750 adults and 200 presumed nests in 2000 are the highest population estimates since the early 1960s (Table 2). Tufts noted that his count of more than 800 individuals in 1964 was less than his estimate from 1933. Bayley (1925) thought there were more than 1000 adults in the 1920s. In contrast, estimates from seabird surveys in the early 1970s and our surveys through the 1980s and early 1990s suggested only about 100 nesting pairs, with lows of less than 50. Because of the difficulty in detecting nests, our surveys were intended to be an index of the number of puffins, rather than a complete count. Considering the counts of presumed nests from 1980 until 1993, there is a strong indication of an increase. However in 1997 the number of presumed nests was extremely low again. The count of 208 in 2000 suggests this was a temporary dip. Like kittiwakes and other seabirds, puffins often abandon nests in years of low food supply, possibly accounting for the low count in 1997.

Table 2 Estimates of the numbers of Atlantic Puffin, Razorbill and Black Guillemot during the breeding season on the Bird Islands, Nova Scotia, 1925 to 2000. The number is an estimate of the number of nests, except those in parentheses which are for individuals. No entry indicates the species was not mentioned or counted that year. A zero indicates a specific acknowledgement that the species did not nest or was not present.

Year	Atlantic Puffin	Razorbill	Black Guillemot	Source
1925	(1000)	(600)	(400)	Bayley 1925
1933	(100s)			Tufts 1962
1940			(40)	Tufts 1962
1964	800+	(200-300)		Tufts 1986
1971	(100-140)			Brown et al. 1975
1976	(90)	(77)		this study
1979	(88)	(69)	(158)	this study
1980	20	69	(151)	this study
1981	(171)	(101)	(76)	this study
1982	35	56	(65)	this study
1984	57	61	(102)	this study
1985	(160)	45		MacDonald 1985
1988	39	104	(149)	this study
1989	47	83	(364)	this study
1990	99	131	(345)	this study
1991	63	82	(107)	this study
1993	107	186	(336)	this study
1995	87	139	(330)	this study
1997	29	215	(346)	this study
2000	208 (760)	180 (591)	(613)	this study

The trends in puffin populations seen on the Bird Islands were lows in the early 1900s, peaks in the 1920s and 30s, declines especially in the 1970s and then recent increases to close to historical maxima. Similar trends have been documented elsewhere in eastern Canada (Nettleship & Evans 1985, Blanchard 1994, Chapdelaine

1995, Chardine 1999b). The Bird Islands host a small, peripheral puffin population. Only a few hundred pairs nest, compared to an eastern North American population of close to 400,000 pairs (Nettleship & Evans 1985, Chardine 1999). Yet this small population shows trends similar to the much larger whole. It may be possible to effectively monitor the large, by focusing on the small.

Common Murre (Uria aalge) Murres were not found in 2000, nor have any been seen on the islands since the 1960s. Bayley (1925) reported 12 pairs in the early 1920s, Taverner found a pair in 1929 (Godfrey 1958) and Tufts found one in 1965 (Tufts 1986). Common Murre populations in the Gulf of St. Lawrence and elsewhere in eastern Canada are doing reasonably well in the past 20 years (Nettleship & Evans 1985, Chardine 1999a) and a few hundred pairs nest as close as the Magdalen Islands (Fradette 1992). Populations were, however, drastically reduced through hunting and harvesting eggs in most colonies in the 1800s (Nettleship & Evans 1985). The Bird Islands are at the southern limit of the range of Common Murres and this is probably part of the reason why this colony has been extirpated, while elsewhere in eastern North America populations have rebounded from low levels in the mid-1900s.

Razorbill (Alca torda) Counts of close to 600 adult Razorbills and 180 presumed nests in 2000 were similar to counts from the 1920s (Bayley 1925) and through most of the 1990s (Table 5). The last four surveys and Bayley's are the five highest totals. In the intervening period both Tufts and our surveys suggest that numbers were lower.

Razorbill population declines were widespread and serious in eastern Canada up until the early 1980s (Nettleship & Evans 1985). Certainly hunting and egg harvesting were major contributing factors historically. However significant decreases continued into the early 1980s. The colonies on the Magdalen Islands were important as a refuge in times of extremely low populations in the early 1900s. They declined by about 85 % between 1960 and 1982. Since that time populations have increased at five of seven major colonies in eastern Canada (Chapdelaine et al. 1999). A similar pattern has been found in some smaller colonies in the Gulf of St Lawrence and Bay of Fundy (Chapdelaine et al. 1999). Certainly there is evidence for recent increases in numbers at the Bird Islands. It is unclear how the present population, or that of the 1920s, compares with numbers that used the islands 200 years ago.

The Razorbills nesting on the Bird Islands represent about 2% of the North American population of 15,000 to 20,000 (Nettleship & Evans 1985, Lock et al. 1994, Chapdelaine et al. 1999). There are relatively few Razorbill colonies in eastern North America because more than two-thirds of the population nests at the Gannet Clusters in Labrador (Nettleship & Evans 1985). Several hundred pairs nest on the Magdalen Islands (Fradette 1992). The combination of few colonies and consistent declines long after protection from hunting and egg collecting make monitoring efforts important for this species.

Black Guillemot (Cephus grille) More than 600 adult Black Guillemots were counted in 2000, the highest recorded for the Bird Islands (Table 6). After a dip in numbers from the late 1970s into the early 1980s, there was a consistent increase through the 1980s. Except for one low count in 1991, numbers remained high through the 1990s, just slightly lower than Bayley's (1925) count from the 1920s. The lowest estimate is Tufts (1962) from a visit to the islands in 1940.

It is difficult to estimate numbers of Black Guillemots because they do not nest in large, discrete colonies, and nests are under a jumble of rocks and thus invisible to people (Nettleship & Evans 1985). In contrast to other alcids in eastern Canada, the data on population trends and size are therefore limited. The overall North American population is estimated to be 50,000 to 100, 000 pairs (Nettleship & Evans 1984). On the North Shore of the St. Lawrence populations increased following legislative protection in the 1920s and then declined after 1965 (Chapdelaine & Brousseau 1984). In the Gulf of Maine numbers increased from 1931 until 1970 and remained stable into the 1980s (Nettleship & Evans 1984).

Discussion

Changes in nesting species Four species that nested on the islands early in the 1900s do so no longer. Two were very numerous, Arctic and Common Terns, a third, Common Murre, was not numerous and the status of the fourth, Leach's Storm-petrel, is unclear. Other species have colonized the islands during this time. Herring Gulls first nested sometime prior to 1954 and Great Black-backed Gulls probably first nested there in the 1950s or early 1960s. The now large colony of Black-legged Kittiwakes was established in 1980. These three recent colonists are now the three most abundant breeding species on the islands. Conversely, in the 1920s the terns vied with Atlantic Puffins as the most abundant seabirds on the islands.

Disturbance Sea bird colonies are concentrated in space and time, therefore populations are vulnerable to local disturbance as well as broader scale disturbances. Boat traffic, changes in fish stocks and oil are thought to be the disturbances most likely to be detrimental to nesting birds on the Bird Islands.

Lobster boats and tour boats have circumnavigated the islands for decades. These boats appear to have little effect on the birds. Most birds do not react to passing boats. A passing Bald Eagle (*Haliaeetus leucocephalus*) attracts far more attention than a lobster boat or a tour boat. Of greater concern are smaller craft (e.g. kayaks) which appear to be noticed and reacted to more frequently than larger boats. However no work has quantified these impressions. We do know that landing on the island when the birds are nesting causes adults to leave nests and if done frequently for extended periods could cause problems. Therefore an enforceable ban on landing on the islands is critical to conservation of the seabird colonies.

Undoubtedly changes in nesting populations both on Bird Islands and elsewhere are at least partially linked with changes in populations of the food supply. The congruence of trends on the Bird Islands for cormorants, Razorbills and kittiwakes elsewhere in the Gulf of St. Lawrence and eastern Canada emphasize the connections. Recent increases in alcid populations have been linked to closures of the groundfishery. With fewer groundfish, more fish may be available for alcids such as puffins (Chardine 1999). Little work has been done, however, to document these interactions between trophic levels. Fishing has co-existed with the nesting colonies for at least 200 years. Recently, the lobster fishery has been intense. We have no evidence of direct links between fishing and bird populations.

A variety of large commercial boats sail the waters in the vicinity of the Bird Islands. With commercial traffic comes the risk of oil spills, large ones from tankers and numerous smaller ones from all vessels. Cargo ships entering the Bras d'Or Lakes pass within a few km of the islands. Many large cargo ships and some oil tankers pass through Sydney Bight to use the port of Sydney, about 30 km from the islands. A major shipping lane connecting the St. Lawrence Seaway and the Atlantic passes through the Cabot Strait, about 70 km to the north. This traffic will result in some oils spills and potential problems for nesting birds. Surveys of beached birds in southern Newfoundland have shown an increase in oiled birds since 1984 (Wiese & Ryan 1999). With the recent interest in exploring for oil and gas offshore of Cape Breton there is a potential for a more serious problem.

Protected Status The owners of the two islands, the Nova Scotia Bird Society and the Province of Nova Scotia, through the Department of Natural Resources, both understand the conservation significance of the islands. Similarly the tour boat operators and the fishers who ply the waters around the islands understand their significance. There is an implicit understanding that the area is protected and that human disturbance, especially during the nesting season, be avoided. Despite this implicit protection, which has worked well for the past 30 years, there is no legal protected status for the islands. It has worked partly because of the interest and efforts of fishers and tour operators to protect what they realize is an important natural resource. NSDNR staff have proposed and written the required justifications, that the islands be declared a Wildlife Management Area. This status would enshrine regulations governing human disturbance on the islands and to codify that landing on the islands be prohibited during the nesting season. A cooperative venture between the two owners could make this happen. Long term effective protection will depend to a large extent on the cooperation and attitudes of the fishers and tour operators who ply the waters daily through the nesting season. The IBA program has worked to promote these goals by encouraging dialogue between the Nova Scotia Bird Society and NSDNR about the Wildlife Management Area proposal, meeting with fishers who use the area, and producing a conservation plan for the islands.

The current large populations of Great Cormorants and Razorbill make this a site of regional conservation importance. Given the change in species composition and populations during the past 75 years, it can be assumed more changes will take place in the future. The significance of the arrival of gulls and the importance of distinguishing which species of cormorants were nesting was not immediately recognized. Ongoing monitoring should attempt to include all species, including new colonists.

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Status and Management of Roseate Terns (*Sterna dougallii*) in Nova Scotia

MARTY LEONARD[1*], ANDREW BOYNE[2] and SHERMAN BOATES[3]
[1] *Department of Biology, Dalhousie University,*
Halifax, Nova Scotia, B3H 4J1
[2] *Canadian Wildlife Service, Environment Canada,*
Dartmouth, Nova Scotia, E4L 1G6
[3] *Nova Scotia Department of Natural Resources,*
Kentville, Nova Scotia, B4N 4E5

The most important breeding colonies for endangered roseate terns in Canada occur on coastal islands in Nova Scotia. The main threat to productivity at these sites appears to be predation, particularly from gulls. The goal of this paper is twofold: 1) to present the results of recent roseate tern surveys in Nova Scotia and 2) to report on the results of a non-lethal gull control program at one of the main breeding sites in the province. The results of the surveys suggest that the number of breeding pairs (approximately 130) in the province has remained relatively stable, and is similar to numbers reported 20 years ago. Breeding sites have, however, fluctuated in number from a high of 10 sites in 1999 to a low of 3 in 2003. Although the concentration of birds to few locations makes some management options easier, it also increases their vulnerability to chance events. The non-lethal gull control program initiated on Country Island in 1998 has proven relatively successful, resulting in an increase in the numbers of breeding common, arctic and roseate terns on the island and a decrease in predation of tern eggs and chicks. Although this program has been effective in reducing predation, it must be maintained in the long-term if these birds are to breed successfully.

Au Canada, les plus grosses colonies de Sternes de Dougall, espèce en voie de disparition au pays, se trouvent sur des îles côtières de la Nouvelle-Écosse. La principale menace à la productivité de ces colonies semble être la prédation, en particulier par les goélands et les mouettes. Le présent document vise deux objectifs : 1) présenter les résultats des récents relevés de Sternes de Dougall en Nouvelle-Écosse et 2) faire état des résultats d'un programme de lutte non mortel contre les goélands et les mouettes mis en œuvre dans un des principaux lieux de nidification de la province. Selon les relevés, le nombre de couples nicheurs (environ 130) est demeuré relativement stable dans la province et est comparable à celui signalé il y a 20 ans. Cependant, le nombre de lieux de nidification a varié, passant de 10 lieux en 1999 à 3 en 2003. La concentration des oiseaux en seulement quelques endroits peut faciliter l'application de certaines méthodes de gestion, mais elle rend plus vulnérables aux phénomènes stochastiques. Le programme de lutte non mortel contre les goélands et les mouettes mis en œuvre en 1998 dans l'île Country a assez bien réussi et y a entraîné l'augmentation du nombre de Sternes pierregarins, de Sternes arctiques et de Sternes de Dougall nicheuses et une réduction de la prédation des œufs et des poussins de sternes. Bien que le programme ait contribué à diminuer la prédation, il faut le maintenir à long terme pour que les oiseaux puissent se reproduire.

General Introduction

Roseate terns breed on coastal islands across six continents. In North America they nest in two distinct areas ranging from the Magdalen Islands to New York and from Florida to the Lesser Antilles (Gochfeld et al. 1998). About 3% of the North American population breeds in Canada, with 95% of these individuals restricted to a few islands in Nova Scotia (Whittam 1998).

In 1986, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated roseate terns as threatened (Kirkham & Nettleship 1985). This designation was based partially on the observed decline in the northeastern U.S. from about 4,800 pairs in 1972 to 2,600 pairs in 1976 (Kress et al. 1983) and on a corresponding decline on Sable Island, Nova Scotia from an estimated 130 pairs in 1971 to 18 birds in 1976

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[*] Author to whom correspondence should be addressed

(Kirkham & Nettleship 1985). Using new criteria developed by COSEWIC, the species has since been reclassified as endangered (Whittam 1998), because its small numbers and restricted distribution make it vulnerable to a variety of environmental threats.

In Nova Scotia the main threat to roseate tern productivity appears to be predation (D'Eon 1998, Whittam & Leonard 1999). Indeed, predation of roseate eggs and chicks by avian predators resulted in the abandonment of Country Island, one of Nova Scotia's most important breeding sites, in 1997 (see below; Whittam & Leonard 1999). Thus, it would appear that the fate of the majority of Canada's roseate terns depends on how predators are managed at critical breeding colonies in Nova Scotia.

The goal of this paper is to highlight some of the work being conducted in Nova Scotia to protect this endangered species. We divide the paper into two sections. In the first section, we provide information on the size and distribution of Nova Scotia's roseate tern population during the last 20 years. In the second section, we report on the results of a non-lethal predator control program initiated on Country Island in 1998.

Population Size and Distribution of Roseate Terns in Nova Scotia

Introduction

Roseate terns have never been common in Nova Scotia, however there is some evidence that the species was more numerous in the first half of the last century (Tufts 1962). Although specific numbers are not provided, there appear to have been a number of roseate terns on Sable Island from 1894 to 1907, and a large colony on Noddy Island in 1906 (Kirkham & Nettleship 1985). About 125 pairs were also reported on Indian Island, Lunenburg County in 1930 (Tufts 1962). By 1970-71, approximately 200 pairs of roseate terns nested at six sites in the province (Sable Island, 130 pairs; Hobson's Nose Island, 28 individuals; Wedge Island, 45 pairs; Tusket Island, present; and an unnamed islet between Calf and Low Islands, 15 individuals), and were believed to have nested on an unnamed island in Boutillier Bay near Spry Point (Lock 1971). Surveys conducted between 1982 and 1985 indicated that between 100 and 120 pairs of roseate terns nested in the province. Thus, most historical information suggests that a relatively stable population of roseate terns, ranging from 100 to 200 pairs, nested in Nova Scotia during the previous century.

Below we report on the results of three intensive surveys conducted in 1995, 1999 and 2003 to locate and count roseate terns in Nova Scotia. For comparison, we also provide the number and distribution of roseate terns located during the only other intensive survey of the province that occurred between 1982 and 1985.

Methods

Tern colonies were identified during aerial surveys of the coastline of Nova Scotia in the summers of 1995, 1999 and 2003. Roughly, 60% of the coastline of the province was surveyed in all three years by the same observer. The survey track was recorded in 1995 using a Garmin™ PCX5 AVD global positioning system, so that the same route could be surveyed in subsequent years. Colonies estimated from the air to contain over 100 terns were visited on the ground because roseates generally nest in larger colonies of arctic (*S. paradisaea*) and common (*S. hirundo*) terns. Sable Island was only surveyed by ground.

Results and Discussion

A total of 96 pairs of roseate terns were counted at five sites in Nova Scotia in 1995, 119-143 pairs at 10 sites in 1999, and 130 pairs at three sites in 2003 (Table 1). Annual

Table 1 Estimated number and location of roseate tern pairs recorded during surveys of Nova Scotia in 1982-85, 1995, 1999 and 2003.

Site	Latitude	Longitude	1982-85 [1]	1995 [2]	1999 [3]	2003 [3,4]
Peter Island	44.258	-66.339	1	1	2	-
Tusket Island	43.650	-66.033	15 - 20	0*	-	0*
Mud Island	43.474	-65.987	2	x	x	x
The Brothers	43.633	-65.825	55 - 60	33	61	86
Salmon Island	43.417	-65.633	-	-	16	0
McNutt's Island	43.633	-65.283	-	0*	1-2	0
Hughes Island	43.733	-65.017	-	0*	5-10	0
Westhaver Island	44.436	-64.338	8	0*	present	0
Mash Island	44.400	-64.233	-	-	10-20	0
Grassy Island	44.750	-64.217	-	30	0*	0
Wedge Island	44.610	-63.948	6	0*	5-10	-
Macdonald Point	44.617	-63.933	-	-	3-6	-
Sambro Island	44.437	-63.563	3	0*	-	0*
Fisherman's Beach	44.667	-63.217	present	-	-	-
Lobster Island	44.910	-62.303	-	-	0	1
Thrumcap Island	44.957	-62.040	present	0*	-	-
Country Island	45.067	-61.533	-	30	16	43
Sable Island	43.950	-59.917	10 - 20	2	x	x
		Total pairs	100-120	96	119-143	130
		Colonies	10	5	10	3

[1] Kirkham & Nettleship 1985, [2] Boates 1995, [3] Boyne 1999, 2003, [4] D'Eon, 2003. 0 = colony visited, but roseate terns not observed, 0* = tern colony present, but < 100 terns, so colony not visited, - = island surveyed from the air, but no tern colony, x = island not surveyed from air or ground

counts between 2000 and 2002 at Country Island and the Brothers reported a total of 131, 71 and 139 pairs of roseates in each year, respectively. Based on the complete survey of the province conducted in 2003 it appears that the large number of roseates nesting on Country Island and The Brothers from 2000 to 2002 represented a contraction of existing birds into a few large colonies, rather than an increase in the population. The results of the 2003 survey are similar to those from the 1982-85 census (i.e. 100 –120 pairs) and suggest that the roseate tern population in Nova Scotia is relatively stable (Table 1; also see Whittam 1998).

The distribution of this population has, however, changed considerably during the last 20 years. For example, surveys from 1982-85 suggest that most roseates were concentrated on Sable Island (10-20 pairs), Tusket Island (15-20 pairs) and The Brothers (55-60 pairs; Kirkham & Nettleship 1985). By 1995, however, roseates were virtually absent from both Tusket and Sable Islands (Table 1) and in 2003, all but one pair of roseates in Nova Scotia nested on either Country Island or The Brothers (Table 1).

The long-term census data indicate that the roseate tern population in Nova Scotia has been relatively stable. With the exception of The Brothers, however, their distribution in the province has been more variable (Fig 1). In some cases the reasons for colony abandonment are known (e.g. Country Island, see below) while in others it is not obvious (e.g. Grassy Island; Table I). Whatever the reason, shifts of this type make roseates difficult to monitor and suggest that regular censuses should include all suitable breeding habitat.

Predator Management and Tern Restoration on Country Island, Nova Scotia

Introduction

Country Island is a 19 ha island located in Guysborough County (45(06'N; 61(32'W; Fig 1) and is the site of a mixed colony of roseate, common and arctic terns. Roseate terns were discovered on Country Island in 1987 and by 1995, it was the location of one of the largest roseate tern colonies in Nova Scotia (see Table I for details). Until 1998, it also supported 20 pairs of great black-backed gulls (*Larus marinus*), 60-90 pairs of herring gulls (*L. argentatus*), two pairs of American crows (*Corvus brachyrhynchos*) and one pair of Northern ravens (*C. corax)*.

In 1996, the tern colony on Country Island suffered heavy predation from corvids and gulls that resulted in nearly complete breeding failure for the 45 pairs of roseate, 130 pairs of common and 330 pairs of arctic terns nesting on the island (Whittam & Leonard 1999). A year later, only one pair of roseate terns and half the common and arctic terns returned to the island. A tern restoration program using non-lethal predator control was, therefore, initiated in 1998 in an attempt to reduce predation on the island and encourage the return of breeding terns. Here we describe the results of the restoration program by reporting on the numbers and some measures of breeding success for roseate terns nesting on the island before (1996, 1997) and after (1998-2002) predator control.

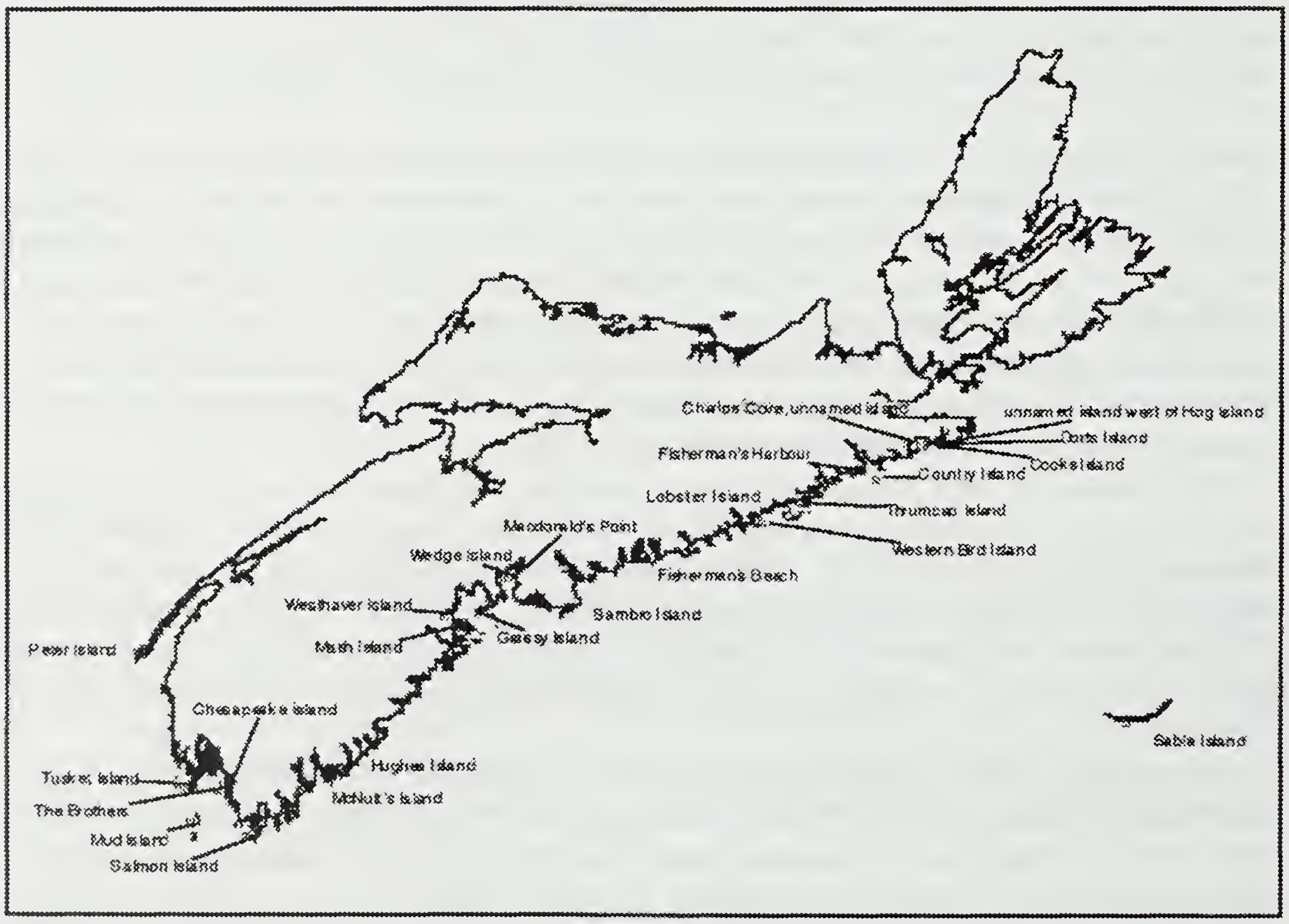

Fig 1 Locations of roseate tern colonies in Nova Scotia occupied at least once between 1982 and 2003 (Whittam 1999, Boyne 2003).

Methods

Predator control and observations:

Before terns arrived, we dispersed adult gulls from the island by firing noisemakers every two hours (1998) or when gulls were loafing on the island (1999 - 2002). Once terns returned to the island, noisemakers were used only when gulls were present. We destroyed all gull and corvid nests discovered during our twice weekly searches.

We conducted daily observations of the tern colony between 0600-0800, 1200-1400 and 1800-2000 and identified each predator entering the colony and whether it took a tern egg or chick.

Roseate tern numbers and reproductive success:

We located tern nests during regular searches of the colony and marked each nest with wooden tongue depressors. We determined the species of tern attending each nest during observations of the colony. A subset of roseate nests was checked approximately every five days to determine clutch size, hatching success and nest fate. We considered an egg to have hatched if a chick was observed at the nest; unhatched if the egg had not hatched within 30 days of being laid; and disappeared, presumed depredated, if the egg could not be found. We determined the fate of chicks during our colony observations by observing feedings at each nest until the end of the dependent period. We considered chicks to have disappeared/ fate unknown if a chick or carcass could not be found after at least two, two-hour observation periods and subsequent searches of the nesting territory, died if a carcass was found and fledged if chicks were observed up to 20 days post-hatch. Our measure of the number of fledglings will be conservative, because the "disappeared" category includes chicks that were taken by predators and died of exposure, but also includes chicks that survived, but moved away from the colony and were not re-sighted.

Results

Predator control:

One hundred pairs of gulls bred on the island before predator control began in 1998, however, none have nested successfully since the control program began. The number of nesting attempts by gulls has decreased since control was initiated (1998: 19, 1999: 11, 2000: 3, 2001: 4, 2002: 3).

Corvids have also not bred successfully on the island since the initiation of the control program, although one pair of ravens and one family of up to five crows have attempted to nest on the island annually. The ravens have made one nesting attempt each year, since the control program began, except for 2002. In years when they did nest, they abandoned the island within 24 hours of the destruction of their nest. The crows, on the other hand, have made multiple nesting attempts/year, although the number of attempts has decreased following control (1998: 9, 1999-2002: 2 each year). Unlike the ravens, the crows continue to frequent the island throughout the tern nesting period.

Finally, the number of tern eggs and chicks of all species lost to predation has steadily decreased following predator control (Table 2), as have the number of predator intrusions and the number of successful intrusions in which the predator took an egg or chick (Fig 2).

Roseate tern numbers and reproductive success:

With the exception of 2001, the number of roseate terns breeding on Country Island has increased since the control program was initiated in 1998. In fact, in 2000 the total number of roseate nests exceeded the pre-abandonment numbers (Table 3). In 2001

Table 2 Colony size (pairs of all tern species), total number of observation hours and number of adults, eggs, and chicks of all tern species taken by corvids, great black-backed gulls and herring gulls on Country Island, before (1996, 1997) and after (1998-2002) the initiation of the predator control program.

Predator species	Year	Hours of Observation	Colony Size	Adults	Eggs	Chicks
Corvid						
Before:	1996	236	505	0	-	0
	1997	319	221	0	48	0
After:	1998	258.5	340	0	2	0
	1999	126.5	568	0	0	0
	2000	138	957	0	1	0
	2001	80	811	0	0	0
	2002	84	969	0	0	0
Great black-backed gull						
Before:	1996	236	505	2	1	69
	1997	319	221	0	7	19
After:	1998	258.5	340	1	3*	14
	1999	126.5	568	0	0	3
	2000	138	957	0	0	32
	2001	80	811	0	0	3
	2002	84	969	0	0	5
Herring gull						
Before:	1996	236	505	0	0	124
	1997	319	221	0	2	34
After:	1998	258.5	340	0	0	13
	1999	126.5	568	0	0	0
	2000	138	957	0	0	0
	2001	80	811	0	0	0
	2002	84	969	0	0	0

* may have been eggs or chicks

only a single pair of roseate terns attempted to nest, despite high numbers of common and arctic terns breeding on the island that year. The reason for this sudden decline is unclear, but appears to have been temporary, as 41 pairs of roseates bred on Country Island in 2002 (Chisholm et al. 2002; Table 3).

Our measures of the number of chicks surviving to fledging (Table 3) should be treated with some caution. Measuring roseate fledging success on Country Island has been problematic because chicks often move away from the main colony and are never resighted. Although some of the chicks that disappear have undoubtedly died, some will have survived. Thus, our estimates of the number of chicks surviving to fledging are likely conservative.

Discussion

The tern restoration program on Country Island has been successful in reducing the number of predators and increasing the number of terns of all species breeding on the island. In general, productivity has also increased following predator management, with common and arctic terns going from complete breeding failure before predator

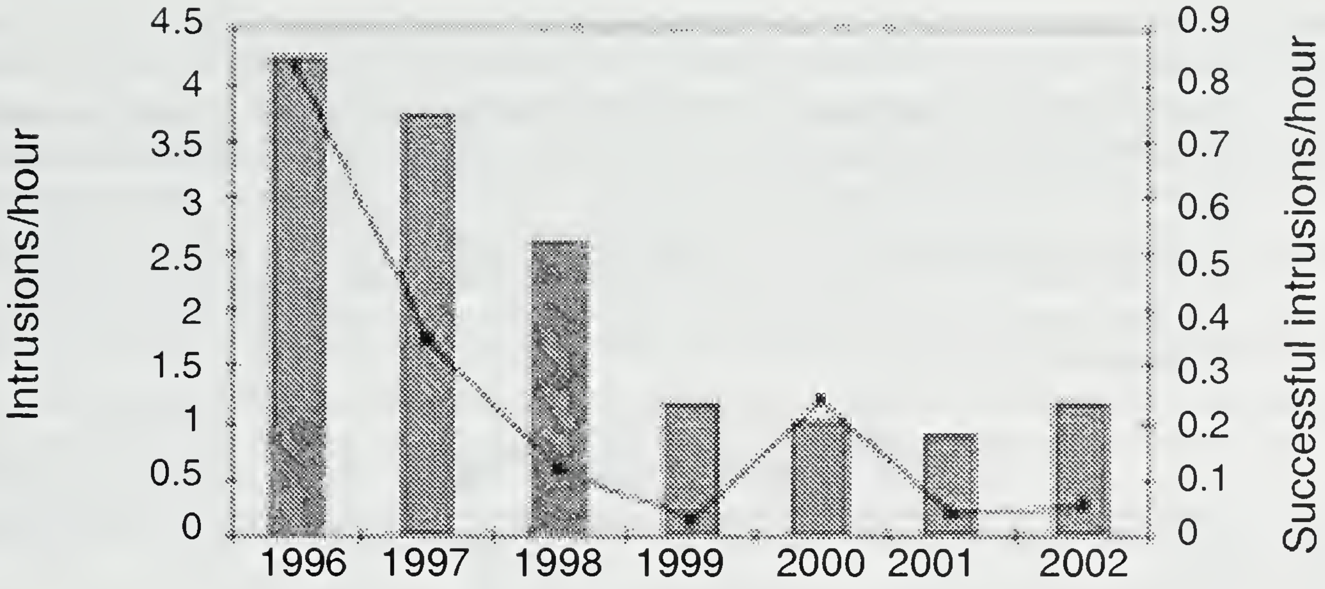

Fig 2 Mean number of predator intrusions (bars) and successful predator intrusions (an egg or chick taken, line) per hour of observation before (1996, 1997) and after (1998-2002) predator control.

control (1996), to an average of 1.41 and 1.08 chicks/nest, respectively, in the years following control (1998-2002). Although roseate tern productivity has been more difficult to measure (see above), it has presumably also increased with the decrease in predation pressure.

Non-lethal gull control is considered to be time consuming, logistically difficult and slow to produce results (Thomas 1972). The immediate success of the program on Country Island is likely due to the relatively small number of predators resident on the island before control began (Smith et al. 2000) and to the speed with which the program was implemented (Kress 1997). Two non-lethal gull control programs have also been recently initiated on the Isle of Shoals, New Hampshire (Deluca 2001) and on Penikese Island, Massachusetts (Nisbet 2001). They, too, appear to be experiencing early success - an effect that may be enhanced by a decrease in the number of gulls, particularly herring gulls, breeding in eastern North America (Chapdelaine 1995, Mawhinney et al. 1999, Boyne et al. 2001, Boyne & Hudson 2002). Although non-lethal control programs require ongoing management to prevent the return of predators (Blokpoel et al. 1997), our results suggest that non-lethal control may be an effective method for managing predators at some seabird colonies.

Predator management appears to be extremely effective in reducing predation and increasing tern reproductive success. Indeed, predator control is considered necessary for the survival of the northeastern population of roseate terns (Nisbet 1981). One potential limitation of these control programs, however, is that when breeding areas are managed for predators the site draws in birds from unmanaged colonies. This tends to concentrate populations into a few, large colonies which then make a larger portion of the population vulnerable to chance events. The benefits of control will generally outweigh these risks, but managers must be vigilant to both anthropocentric and environmental hazards that could put these large colonies at risk.

Although predation is the main factor limiting productivity of roseate terns in Nova Scotia, other factors may also influence reproductive success. For example, roseate terns are susceptible to human disturbance early in the breeding cycle (Nisbet & Drury 1972), so breeding colonies on or near the mainland are particularly vulnerable. Management of offshore islands for predators may, however, draw these birds to safer breeding habitat (see above). If not, then inshore colonies should be marked with signs advising the public to avoid disturbance to the area during the breeding season.

Table 3 Fate of roseate tern eggs and chicks on Country Island before (1996, 1997) and after (1998, 1999, 2000) predator control. Total number of roseate tern nests, number of nests monitored to determine fate of eggs and chicks, total number of eggs laid, number that disappeared, number unhatched, mean hatching success (eggs hatched/nest), number of chicks, number that disappeared (includes chicks that were depredated, died of exposure and carcass not recovered, and chicks that survived, but moved away from the colony and were not re-sighted), number dead (carcass recovered), and number fledged on Country Island (adapted from Jensen et al. 2000, Smith et al. 2000, Chisholm et al. 2002).

	Before		After				
	1996	1997	1998	1999	2000	2001	2002
Number nests	45	1	3	16	53	1	41
Nests monitored	45	1	3	12	31	1	39
Eggs laid	75	1	3	18	47	1	48
Eggs disappeared	18	0	0	0	0	0	0
Eggs unhatched	10	1	1	0	8	1	5
Hatching success	1.04	0	0.67	1.00	0.83	0	0.90
Number of chicks	31*	0	2	21	39	0	43
Disappeared/ unknown	24	-	2	19	23	-	36
Died	5	-	0	0	6	-	2
Fledged	2	-	0	2	10	-	5

* chicks were followed from 24 nests only

In conclusion, most of Canada's endangered roseate terns breed in Nova Scotia. Much of the management effort for this species should, therefore, be directed toward colonies in this province. Current predator control programs appear successful, but management and monitoring of tern breeding colonies must be ongoing to ensure that populations remain stable, or potentially increase.

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THE DISTRIBUTION, STATUS AND HABITAT ASSOCIATIONS OF MOOSE IN MAINLAND NOVA SCOTIA

TAMAINI V. SNAITH AND KAREN F. BEAZLEY*
School for Resource and Environmental Studies,
Dalhousie University,
Halifax, Nova Scotia, Canada B3H 3J5

Throughout the Nova Scotia mainland, small and fragmented moose populations remain at varying densities and may be limited or regulated by a number of factors including interspecific competition, disease, habitat alteration/loss, mineral toxicity/deficiency, predation, poaching, and resource availability. Ranging behaviour and habitat requirements vary according to environmental factors; however, moose require food and cover in sufficient quantity and of appropriate interspersion to meet their daily and seasonal needs. Mature forest with a well developed understory, and open areas with early successional vegetation provide forage, while dense forest provides cover from thermal stress and deep snow. Strategies for moose conservation, such as through forest management, should concentrate on the preservation and enhancement of habitat to meet the critical requirements of viable moose populations and the re-establishment of connections among discrete populations.

Sur la terre ferme en Nouvelle-Écosse, il reste de petites populations fragmentées d'orignaux de densités variables qui sont peut-être limitées ou régulées par plusieurs facteurs dont la compétition interspécifique, les maladies, l'altération ou la destruction des habitats, la toxicité des minéraux ou le manque de minéraux, la prédation, le braconnage et la disponibilité des ressources. Les déplacements et les besoins en matière d'habitat des orignaux varient en fonction des facteurs environnementaux; cependant, les orignaux ont besoin de nourriture et d'un couvert adéquatement repartis pour satisfaire leurs besoins quotidiens et saisonniers. Les forêts matures à sous-étage bien développé et les zones ouvertes caractérisées par des espèces végétales pionnières fournissent la nourriture, tandis que les forêts denses offrent un couvert contre le stress thermique et la neige épaisse. Les stratégies de conservation des orignaux, par exemple associées à l'aménagement des forêts, devraient viser principalement la conservation et l'amélioration de l'habitat de manière à combler les besoins essentiels des populations viables d'orignaux, ainsi que le rétablissement de la connectivité entre les populations disjointes.

Introduction

Over the past few centuries, Nova Scotia has undergone extensive habitat conversion, degradation, and fragmentation as a result of increasing urbanization, agricultural development, and resource extraction. As a consequence of human exploitation and habitat loss, many elements of Nova Scotia's biodiversity are at risk and a number of local species have become endangered or extirpated (COSEWIC 2000). Mainland moose (*Alces alces americana*) are among the species at risk in Nova Scotia (CESCC 2001). To understand current threats to moose, and to plan for their conservation, it is necessary to determine the status and distribution of populations throughout the province, to understand the habitat relationships of the species, and to examine the range of factors which may be threatening or regulating the population. Little is published describing the population dynamics and habitat associations of moose in Nova Scotia, and to date there has been no attempt to synthesize what is known in Nova Scotia with information gathered from moose populations elsewhere. Thus, the purpose of this paper is to synthesize the available information describing the distribution and status of moose in mainland Nova Scotia, their critical habitat requirements, and factors contributing to their decline.

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* Author to whom correspondence should be addressed

Moose Distribution in Nova Scotia

Historically, moose were abundant throughout Nova Scotia; however, there have been fluctuations and general declines in moose numbers since the early seventeenth century (Dodds 1963, Pulsifer & Nette 1995). By the early twentieth century, moose were completely extirpated from Cape Breton, and reduced to a few localized populations on the mainland (Pulsifer & Nette 1995). When indigenous moose failed to recover in Cape Breton, 18 individuals (*A.a. andersoni*) were introduced from Alberta in 1948/49 and the population increased steadily to about 4000 individuals by the late 1980s (Dodds 1963, Kelsall 1987, Pulsifer 1995, Pulsifer & Nette 1995, Timmermann & Buss 1997). Currently, there may be more than 5000 moose in Cape Breton (Nette 2000). During the same period, remnants of the indigenous moose herd on the mainland continued to decline, and now moose remain in significant numbers in only two areas (Figure I) (Pulsifer & Nette 1995, Nette 2000, Pulsifer 2000, Hall 2000). The northeastern mainland population, concentrated mainly in the Cobequid Highlands, consists of around 500 individuals (possibly as many as 800) but is thought to be declining, while the southwest population is thought to be stable at around 300 individuals, with its core occupying the Tobeatic region. In addition, there are scattered pockets of moose throughout much of the mainland, including no more than 100 individuals in the Pictou/Antigonish Highlands. Currently, the total population on the mainland is about 1000 individuals (Kelsall 1987, Pulsifer & Nette 1995, Nette 2000, Pulsifer 2000, Hall 2000). Due to the small and fragmented nature of the population, mainland Nova Scotia moose are at risk of extirpation, and have been red-listed in the province (CESCC 2001). In light of this present threat, the focus of this paper is on mainland moose populations.

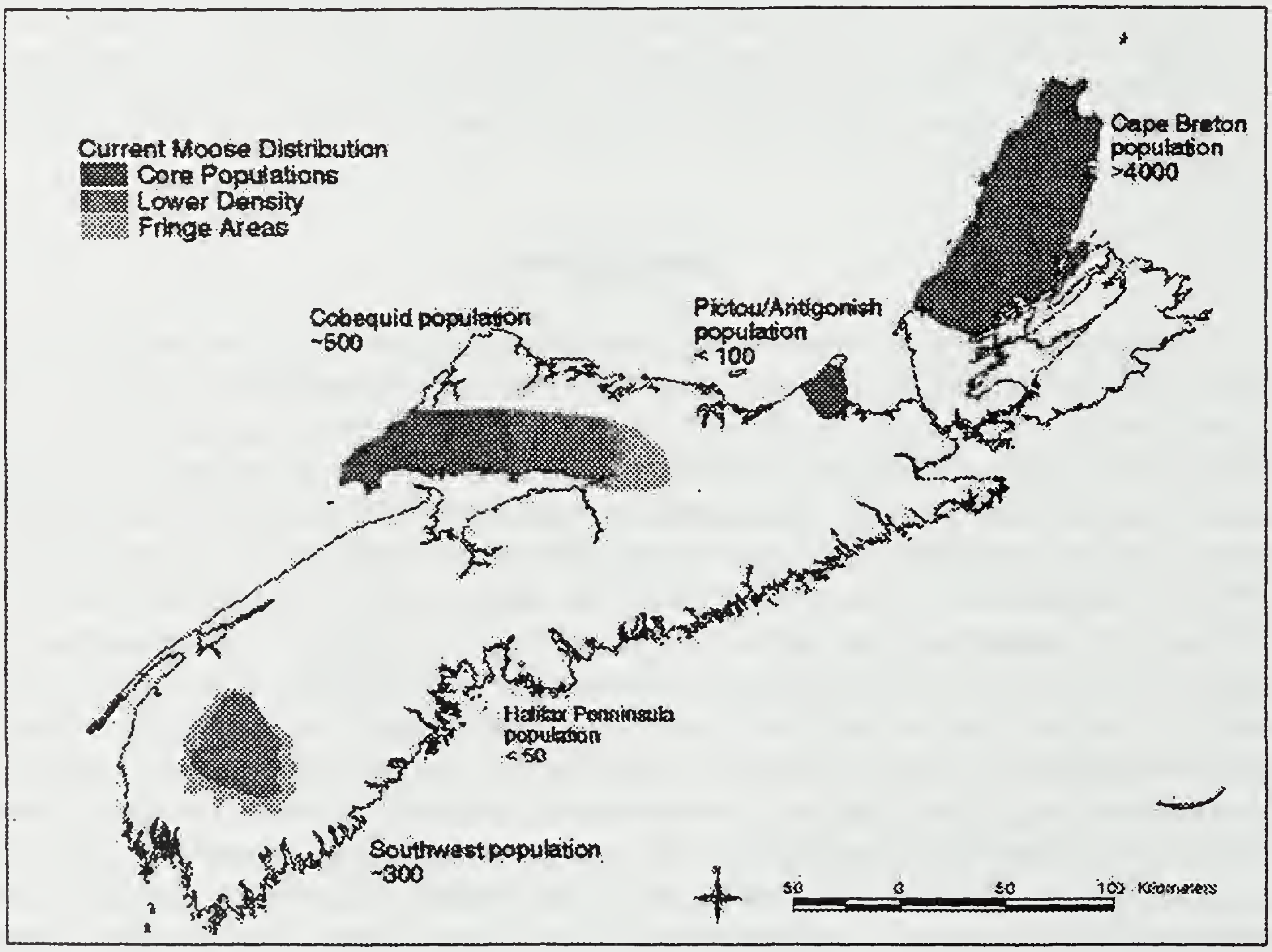
Current Moose Distribution
▩ Core Populations
▩ Lower Density
▨ Fringe Areas
Cape Breton population >4000
Cobequid population ~500
Pictou/Antigonish population < 100
Halifax Peninsula population < 50
Southwest population ~300
50 0 50 100 Kilometers

Fig 1 Current Moose Distribution in Nova Scotia

Moose Habitat Requirements

Moose require large areas and a diverse landscape to provide the resources essential for their survival (Appendix 1). The specific habitat requirements of moose in Nova Scotia have not been documented in detail. A synthesis of available information, in addition to data from populations elsewhere, will provide useful information about habitat use, ranging behaviour, and area requirements. The following sections summarize what is known about the nutritional, cover and habitat area requirements of moose, and the data is applied to the bioclimatic conditions of Nova Scotia.

Nutritional Requirements

Early successional deciduous vegetation is the primary source of moose forage, particularly during the spring and summer (see Appendices 1, 2 and 3 for references). The understory of mature forest and open areas following disturbance such as windthrow, insect damage, wildfire or forest harvesting often contain good moose forage. During the summer, moose consume a variety of terrestrial and aquatic foods including deciduous leaves, shrubs, grasses, forbs, aquatic vegetation, and young plant growth high in digestible energy and protein (Regelin et al. 1987, Timmermann & McNicol 1988). During this time, energy is required for lactation, growth, antler production, and fat storage to ensure winter survival (Timmermann & McNicol 1988).

During the winter, food intake generally decreases because food resources are limited to poorly digestible woody browse of low nutritional quality, and may be difficult to access due to snow cover and thermal stress (Coady 1974, Belovsky 1981, Schwab 1985, Schwartz et al. 1987, DelGiudice et al. 1997). Conifer consumption is likely dependent on the amount of deciduous browse available, becoming increasingly important as winter progresses or in areas where preferred species are less prevalent (NSDLF undated, Benson 1957, Knowlton 1960, Des Meules 1964, Prescott 1968, Telfer 1984, Cederlund & Markgren 1987, Timmermann & McNicol 1988, Histol & Hjeljord 1993).

Important food species in Nova Scotia include red, sugar, and mountain maple, white and yellow birch, hazelnut, and balsam fir (Appendix 2) (Benson 1957, Telfer 1967a, b, Prescott 1968, Basquille & Thompson 1997). In Nova Scotia, quantitative field studies have demonstrated that moose rely on maples for up to 50% of their winter diets, and birch for approximately 20% (Telfer 1967b, Prescott 1968). Mountain maple is the most important food species and is browsed heavily whenever available (Prescott 1968). The amount of balsam fir consumed varies from very little to 50% of the diet or more (Benson 1957, Telfer 1967a, b, Prescott 1968, Basquille & Thompson 1997).

Aquatic vegetation is an important component of moose summer diets in many areas (see Appendix 1 for references). However, wetlands are infrequent in the Cobequid area, and aquatic systems in the southwestern region are generally too acidic to support much vegetation (Morash 2000, Nette 2000). Moose have nevertheless historically persisted in these areas, suggesting that aquatic vegetation is not a critical dietary requirement in Nova Scotia (Telfer 1984).

Based on food species preferences and the vegetative characteristics of Nova Scotia (Loucks 1962, Rowe 1972, Ecological Stratification Working Group 1995, NSDOE 2000, Nette 2000), the Cobequid moose population occupies highly suitable habitat containing a wide variety of preferred hardwood species and occasional wetlands containing aquatic forage. The southwestern population inhabits a less-than-ideal area where the rocky barrens contain fewer hardwood species and are less productive due to poor soils. Although lakes and wetlands are more frequent than in the Cobequid region, aquatic vegetation is limited due to high levels of wetland acidity.

Cover Requirements

Vegetative cover is a critical element of moose habitat during all seasons and is necessary for thermoregulation and protection from sun, snow, wind, extreme cold, and predators. Thermal cover (closed-canopy, dense, mature forest at least 30 years old) is necessary to protect moose from heat stress because although moose are well-adapted to cold weather, they are sensitive to hot temperatures (Peterson 1955, Coady 1974, Renecker & Hudson 1986, Schwab & Pitt 1991).

Due to thermal radiation, moose cannot comfortably withstand temperatures above approximately 14 to 20°C in the summer and -5 to 0°C in the winter (Renecker & Hudson 1986). When temperatures reach these levels, moose restrict their activity and seek cooler micro-environments under dense forest cover or in water bodies (see Appendix 1 for references). Average summer temperatures in Nova Scotia reach about 15°C (Ecological Stratification Working Group 1995), which is within the critical range and is probably enough to necessitate the presence of forest cover throughout the summer months. An on-going study of moose in the Tobeatic indicates that moose preferentially select dense, mature deciduous forest habitat during the summer months (Nette 2000). The average winter temperatures of -1.5°C in the southwestern region and -2.5 to -5.5°C in the Cobequids (Ecological Stratification Working Group 1995) are well within the critical range and will create heat stress during the winter, forcing moose to seek shelter from thermal radiation.

In addition to thermal/heat stress, moose require cover to avoid extreme cold and deep snow conditions. As winter progresses moose move into mature conifer-dominated stands which provide the greatest protection from snow, cold, and heat. In Nova Scotia, moose move to sheltered areas during late winter regardless of snow conditions (which rarely reach critical conditions), presumably to alleviate thermal stress (Nette 2000). Moose winter concentration areas, or yards, in the Cobequid Hills of Nova Scotia were described by Prescott (1968) and Telfer (1967a, b) as the most intensively used portions of moose winter range. They are located on the upper third (at 120 m to 180 m elevation above sea level) of south-facing slopes where temperatures are mild, and are selected for forage availability as well as dense forest cover for snow, wind, and sun protection. The yards are located where the softwood slopes meet the hardwood hilltops which provides a high diversity of vegetation types and the necessary combination of food and shelter.

Security cover (dense vegetation at least 2 m high) is essential year-round to escape predators and for successful reproduction and calf-rearing (Knowlton 1960, Thompson & Euler 1987, Miquelle et al. 1992, Nette 2000). Cows seek secluded areas for calving, such as isolated patches of dense vegetation and islands or peninsulas which offer security from predators (Peterson 1955, LeResche et al. 1974, Taylor & Ballard 1979, Towry 1984, Leptich & Gilbert 1986, Allen et al. 1987, Cederlund et al. 1987, Timmermann & McNicol 1988, Miquelle et al. 1992, Puttock et al. 1996, Bowyer et al. 1999). Calving sites are typically close to open areas with high forage availability, are well sheltered from predator attack, and are near a source of water (Bowyer et al. 1999, Leptich & Gilbert 1986, Allen et al. 1987). Lowland bogs, islands, or peninsulas with thick cover are ideal and will provide protection for vulnerable calves. Water bodies provide drinking water, refuge from flies and predators, and a cooling mechanism during the hot summer months (van Ballenberghe & Peek 1971, Peek et al. 1976, 1987, Dunn 1976, Kearney & Gilbert 1976, Telfer 1984, Ackerman 1987, Joyal 1987, Timmermann & McNicol 1988, Bontaites & Gustafson 1993).

The Cobequid region, with frequent densely forested areas, and varied topography where mild microhabitat conditions can usually be found, likely provides habitat with adequate cover for moose. In the more barren southwestern region, moose must rely on less frequent and less dense forest stands for cover, but have greater access to water bodies.

Seasonal Habitat Selection

Based on the literature, the habitat requirements of moose in Nova Scotia can be summarized as follows:

Spring and early summer (April to early June): Moose require open or disturbed areas with lots of good quality forage, calving areas, and forest cover for thermal and predator protection. If available, aquatic vegetation may provide essential nutrients. Mixed habitat providing a combination of food, cover, and water bodies will provide good moose range during the spring and early summer.

Summer (mid-June to early September): During the hottest months of summer, moose require dense forest cover for protection from heat stress, and forage-rich areas which will provide enough food for growth, lactation, and fat storage requirements. Forest edges and open areas in close proximity to dense cover will provide good forage and easily accessible protection from solar radiation. Aquatic sites (for food, escape, and cooling) may be important habitat components during the summer. However, the availability of good aquatic resources is limited in Nova Scotia. Good summer habitat contains an interspersion of densely forested stands and forage producing areas such as mixed or disturbed forests with relatively open canopies or mature forests with understory for forage production.

Fall and early winter (mid-September to early January): Moose will continue making use of forage-rich areas as long as weather and snow conditions allow. Cover is less important during this time because solar radiation decreases and snow does not reach critical levels. Open and disturbed habitat with early successional vegetation is preferred during the fall and early winter.

Late winter (mid-January to late March): Dense cover again becomes critical during the late winter as snow accumulates and temperatures become extreme. Heat stress due to solar radiation, along with wind chill and deep snow, can restrict moose to densely forested areas during the late winter season. The best winter habitat will also include an interspersion of forage-rich areas such as small disturbances and forest edges.

Effects of Forest Disturbance and Management on Moose Habitat

Forest disturbances result in canopy openings which allow light penetration and natural regeneration (McNicol 1990). Early successional vegetation resulting from disturbances provides good moose forage and moose are often found at their greatest densities in areas where disturbance has occurred (Peterson 1955, Peek 1974a, Peek et al. 1976, Oldemeyer & Regelin 1987, McNicol 1990). Favourable browsing conditions exist in regenerating stands of about 5 to 40 years old, with a peak around 7 to 15 years post-disturbance (see Appendix 3 for references). Suitable cover, however, will not return for at least 30 years post-disturbance (Telfer 1970b). It is therefore essential to maintain residual stands of cover adequately dispersed throughout disturbed areas.

Natural Disturbance Regimes

Natural disturbance regimes can provide sufficient moose forage effectively interspersed with dense forest cover. Small-scale natural disturbances in mature forest continually open up the canopy and produce good understory vegetation which provides excellent forage (Houston 1968, McNicol & Gilbert 1987, Oldemeyer & Regelin 1987, Heikkila et al. 1996). Riparian habitat and floodplains undergo constant disturbance and succession, providing forage on a permanent basis (Houston 1968, Peek 1974a, Sumanik & Demarchi 1977, Doerr 1983, Oldemeyer & Regelin 1987, MacCracken et al. 1997).

Wildfire may kill or force some animals out of their range, but normally leads to browse improvement and better interspersion and heterogeneity of resources (Dodds 1974, Crawford 1993). Small burns are generally beneficial; however, severe and repeated burning can be detrimental to moose range and has produced areas of ericaceous vegetation in western Nova Scotia which are poor quality moose habitat (Dodds 1974, Muise 2000).

Forest diseases and insect damage, such as birch die-back and spruce budworm (*Choristoneura fumiferana*) infestations, can lead to habitat degradation through partial or complete defoliation (Prescott 1968, Dodds 1974). Such disturbance leads to regeneration, however, and is often beneficial to moose range by producing early successional vegetation interspersed with sufficient cover (Prescott 1968, Dodds 1974, Crawford 1993). A spruce budworm infestation in the Cape Breton Highlands led to regeneration of preferred forage species, while sufficient thermal cover was maintained, and is associated with a large increase in moose densities in the area (Basquille & Thompson 1997).

Forest Management

Forest management can enhance or degrade habitat for moose. For example, regenerating clearcuts provide good moose browse after 10 to 40 years; however, large cuts do not provide optimal moose habitat due to increased homogeneity and the reduction of critical thermal and escape cover (see Appendix 3 for references). Moose will not make use of available forage in large open areas which do not contain residual stands of mature forest cover, and generally will not move more than about 80 to 200 m from cover, particularly during periods of deep snow (Eastman 1974, Hamilton et al. 1980, Tomm & Beck 1981, Allen et al. 1987, Peek et al. 1987, Jackson et al. 1991, Thompson et al. 1995). Studies have demonstrated that moose will not begin to preferentially use cutovers until 10 to 15 years post-cut, when some degree of forest cover has returned, even if forage is available in the cuts prior to this period (Monthey 1984, Potvin et al. 1999).

Silvicultural practices which favour establishment of single-species coniferous stands do not produce desirable food species for moose, and often include the use of herbicides (Prescott 1968, Peek et al. 1976, Joyal 1987). Glyphosate is commonly used on clearcuts in Nova Scotia to discourage deciduous growth in favour of merchantable conifer species which do not provide high quality moose forage (Escholz et al. 1996, Raymond et al. 1996). Studies have produced conflicting results regarding the effects of glyphosate on moose habitat (Connor & McMillan 1990, Escholz et al. 1996, Raymond et al. 1996, Hjeljord 1994, Santillo 1994), and the effects of glyphosate ingestion on the health of wildlife are unclear, although Raymond et al. (1996) suggested that toxic effects are minimal.

Large-scale harvesting that leaves few stands of mature forest and cultivation of even-aged, single-species stands reduce and fragment moose habitat and result in forest homogeneity. Timber harvest by selective or partial cutting can enhance moose habitat by producing an interspersion of food producing areas within an adequate supply of shelter (Prescott 1968, Telfer 1984, Cederlund & Sand 1992, Pulsifer 1995). In general, forest management for moose habitat should maintain at least 55 to 70% mature cover-providing forest distributed in patches no smaller than about 8 ha, and should retain some large patches of residual cover (up to 100 ha) with disturbances designed so there is never more than 200 m to cover from any point (see Appendix 3 for references).

Land Development

Human settlement and development, land clearing, cultivation, urbanization, and recreational development restrict and eliminate moose habitat (Houston 1968, Dodds 1974). Roads, trails, and other utility corridors provide access for competitors and predators, increase hunting pressure, fragment and convert habitat, disturb wildlife during construction and use, and increase mortality by vehicle collision (Houston 1968, Prescott 1968, Peek et al. 1987, Hogg 1990, Forman et al. 1997, Jalkotzy et al. 1997, Rempel et al. 1997). Although roads may provide open forage-producing areas, moose frequently do not take advantage of the increased forage availability, and any benefits are offset by associated disturbances and increasing mortality rates (Timmermann & Gollath 1982, Forman et al. 1997, Jalkotzy et al. 1997). Analysis of pellet group data indicated that moose in mainland Nova Scotia preferentially select areas with few or no roads, and less frequently occupy areas of high road density (Snaith 2001, Beazley et al. 2004). Thus, the retention of areas of low road density, such as in the Tobeatic area, and the decommissioning of forestry harvesting roads after use may be critical to the maintenance of moose populations in Nova Scotia.

Moose Ranging Behaviour and Area Requirements

Globally, moose show considerable variation in their ranging patterns and home range size (Appendix 4). This variation is likely due to the variability among sites in climate, range quality, and the degree of interspersion of essential habitat components. Annual home range sizes reportedly vary from 12.6 km^2 in Sweden where the habitat is of excellent quality with small-scale disturbances, a mixture of successional stages, and high resource availability (Cederlund & Okarma 1988), to 200-500 km^2 in Alaska and the Northwest Territories where moose are forced to travel much further to meet their daily and seasonal requirements (Taylor & Ballard 1979, Ballard et al. 1991, Stenhouse 1995). Population density tends to be greater in areas with good habitat quality where individuals occupy smaller home ranges (Sweanor & Sandegren 1989).

There are few estimates of home range size and range use patterns for moose in Nova Scotia. Preliminary results of an ongoing study indicate that moose in the southwestern population occupy a mean annual home range of 55.2 km^2 with overlapping seasonal ranges (n = 8; r = 13.29-129.84 km^2; based on two years of observation and 51 to 63 relocations/individual) (calculation based on figures from Brannen (2000)). There are no estimates for home range size of individuals in the more mountainous habitat of the Cobequids. However, data from similar habitat areas in Maine and the Gaspé Peninsula suggest that widely separated seasonal ranges are not necessary, and that home ranges vary from 20 km^2 to 50 km^2 (Dunn 1976, Crossley & Gilbert 1983, Crete 1989, Leptich & Gilbert 1989, Thompson et al. 1995) (Appendix 4). Because moose are known to adapt to widely distributed resources by ranging over large areas (Lynch & Morgantini 1984), it is possible that the reported area requirements in the southwest region of Nova Scotia are slightly larger than estimates from Maine and the Gaspé Peninsula because resources are more sparse in the rocky barrens characteristic of southwest Nova Scotia.

Nova Scotia moose do not exhibit long-distance seasonal migrations; however, local seasonal movements do occur in response to food availability and snow conditions, especially in the mountainous Cobequid region (NSDLF undated, Benson 1957). Winter home ranges are much smaller than summer ranges because movement is restricted due to lower food availability and the constraints of travel associated with snow accumulation (Telfer 1967a, b). Moose winter ranging behaviour in the Cobequids is characterized by localized concentrations of moose in yards which are small, intensively used areas within a restricted winter range of 2.6 km^2 (Telfer 1967a, b). Summer range requirements are much larger due to increased travel associated with feeding activities. Based on the literature cited above, and the ongoing study in the Tobeatic, 20 to 50 km^2 of good habitat is likely a conservative estimate of the area required by an individual moose.

Population Density

Worldwide, there is generally a great range of variation in moose population density (Appendix 4), and it is difficult to determine the ideal density and structure of a healthy population. Although current average densities are not known, mainland moose populations are at much lower densities than they have been in the past (NSDLF undated, Benson 1957, Dodds 1963, 1974, Telfer 1968b, Prescott 1968, Pulsifer 1995, Pulsifer & Nette 1995, Timmermann & Buss 1997). Traditionally, the highlands of the northeastern mainland have maintained the greatest moose densities, and likely still do, although some evidence indicates that there are a few local concentration areas with relatively high densities in the Tobeatic (Benson 1958, Dodds 1963, Prescott 1968, Nette 2000). Currently, population density in the Cobequid Highlands is estimated to be 0.01 to 0.09 moose/km^2, while in the southwest, population density is approximately 0.05 moose/km^2 or less, with local concentrations of up to 0.35 moose/km^2 (Pulsifer & Nette 1995, Nette 2000).

Moose populations elsewhere exist at similarly low densities, and are likely maintained at low levels due to poor range conditions, restricted sodium availability, reduction of winter habitat due to forest management, hunting mortality, and predation pressure (for example, *Former Soviet Union*: Filonov & Zykov 1974, Kistchinski 1974, Syroechkovskiy & Rogacheva 1974; *Newfoundland*: Albright & Keith 1987; *Labrador*: Chubbs & Schaefer 1997; *Northwest Territories*: Stenhouse 1995; *Quebec*: Brassard et al. 1974, Joyal & Sherrer 1978, Crete & Courtois 1997; *Ontario*: Thompson & Euler 1987, Duinker et al. 1996; *Alberta*: Hauge & Keith 1981; *Alaska*: MacCracken et al. 1997). These factors, among others as described below, may be acting to limit or regulate Nova Scotia moose populations, and must be carefully considered when assessing population viability or designing conservation and management plans for moose habitat.

Regulating Factors

Habitat Suitability and Degradation

In some areas, moose show density-dependent population regulation based on resource availability. Reproductive rates and survival are linked to nutritional status, and poor range conditions lead to lower body weight, slower development, delayed sexual maturity, lower calf production, and increased mortality (NSDLF undated, Messier & Crete 1984, Franzman & Schwartz 1986, Fowler 1987, Karns 1987, Page

1987, Andersen 1991, Wallin et al. 1995, Sand et al. 1996, Crete & Courtois 1997, Saether 1997, Hjeljord & Histol 1999). Some studies suggest that winter food availability is an important limiting factor affecting mortality rates, population density, and carrying capacity (Stevens 1970, Peek 1974b, Crete & Jordan 1982, Albright & Keith 1987, Cederlund & Markgren 1987, Crete 1989, Andersen 1991, Ballard et al. 1991). However., a number of reports suggest that food availability is not likely a limiting factor for moose, even during winter (Crete & Jordan 1982, Messier & Crete 1984, Miquelle et al. 1992, Joyal 1987, Bontaites & Gustafson 1993, Saether et al. 1996). Hjeljord & Histol (1999) suggest that density-dependent resource limitation is unlikely to occur until moose reach very high densities. The *quality* of food resources or the presence of other critical habitat components, such as adequate cover, may be more important factors affecting moose population densities and distribution (Oldemeyer 1974, Peek 1974b, Regelin et al. 1987, Miquelle et al. 1992, Puttock et al. 1996).

Population stability is also affected by fluctuations in habitat characteristics due to disturbances such as blow-downs, fires, forest management and insect infestations, which influence forage production (Telfer 1984, Bobek & Morow 1987, Cederlund & Sand 1991, Bontaites & Gustafson 1993). Habitat disturbance at a large scale may restrict or significantly fragment moose habitat, particularly thermal cover, which may lead to decreasing moose populations while at the same time favouring the expansion of deer, a possible competitor (Telfer 1970b, Dodds 1974, Bontaites & Gustafson 1993, Pulsifer 1995). Forest conversion for agriculture, industry, and urbanization have led to the reduction and extirpation of moose in portions of Europe, the United States, Nova Scotia, Ontario, and Quebec (Dodds 1974, Telfer 1984). Continuing forest conversion, degradation and fragmentation in Nova Scotia, including through forest harvesting, may decrease habitat suitability and availability, and further increase pressure on moose populations.

Climate

Seasonal climatic fluctuations affect moose health, and in extreme cases may limit populations directly by increasing mortality, or indirectly by affecting food availability. Severe winter weather, and heat stress during hot summers, may cause decreased forage intake and increased energy expenditures for thermoregulation which in turn might decrease fat storage and ultimately increase winter mortality (Renecker & Hudson 1986, Ackerman 1987). Because Nova Scotia is near the southern limit of moose range, heat stress likely occurs during both late winter and hot summer months. Summer and winter thermal stress, if combined with a lack of adequate mature forest for thermal protection and few aquatic resources, may be an important factor affecting moose populations in the province.

The current global warming trend has the potential to greatly affect moose populations in Nova Scotia, which are already close to the limit of heat tolerance. A period of rapid human-induced atmospheric and climate change will lead to changes in range conditions and may decrease habitat quality (Peters & Darling 1985, Graham 1988, Hunter et al. 1988, Davis & Zabinski 1992, Dawson 1992, Lovejoy 1992, Murphy & Weiss 1992, Peters 1992, Shugart & Smith 1992). The effects of these changes will be compounded by an increasingly developed landscape where there are physical barriers to animal movement and few remaining connected natural areas for dispersal.

Moose Interactions with White-Tailed Deer

Northward expansion of white-tailed deer (*Odocoileus virgianus*) populations into areas traditionally occupied by moose has been associated with increasing human-induced environmental change. White-tailed deer are highly adaptable and prefer deciduous forest habitat and forest edges associated with open areas (Anderson 1972). Over the past 150 to 200 years, agricultural and linear corridor development and forest management practices throughout Nova Scotia have opened up the forests, creating browse and cover conditions suitable for deer (Anderson 1965, 1972, Karns 1967, Prescott 1974, Lankester 1987). White-tailed deer appeared in Nova Scotia in the late nineteenth century and became the dominant cervid by the mid-twentieth century, while moose numbers dwindled (Benson 1958, Telfer 1967b, Anderson 1972, Pulsifer 1995). Similar trends have been reported for New Brunswick (Telfer 1968a), Maine (Gilbert 1973, 1974), Ontario (Anderson 1965, Saunders 1973) and Minnesota (Karns 1967). These declines in moose numbers have often been attributed to a sickness caused by the parasitic nematode, *Paralephostrongylus tenuis*, normally associated with white-tailed deer. However, the initial habitat alterations themselves, or the increased interspecific food competition subsequent to the increase in deer density may also have been significant factors in the reduction of moose numbers (Wright 1956, Benson 1957, Telfer 1970b, 1984, Banfield 1974, Prescott 1974, Strandgaard 1982, Telfer & Cairns 1986, Karns 1987, Pulsifer 1995).

Direct food competition may be unlikely because moose and white-tailed deer are frequently separated by differential habitat selection (Telfer 1967b, 1968a, 1970a, Gilbert 1974, Telfer & Cairns 1986, Kearney & Gilbert 1976). In many cases, spatial separation occurs during the winter months. Because deer are less tolerant of snow, they are forced to move to lower altitudes or into more dense conifer cover than is required by moose (Telfer 1968a, Tierson et al. 1985). However, forest conversion associated with the creation of roads and open areas, as well as climate warming trends, may continue to favour deer populations over moose.

Disease

Moose populations in Nova Scotia may be significantly affected by a number of diseases including brainworm (*P.tenuis*), winter ticks (*Dermacentor albipictus*), and nutritional deficiencies or toxicity due to environmental contamination. *P. tenuis* is a common parasite of white-tailed deer in eastern North America, and can be transmitted to moose via terrestrial gastropods (snails), the intermediate host (Anderson 1963, 1972). White-tailed deer can tolerate the parasite without any pathogenic symptoms. However, *P. tenuis* is highly pathogenic and often fatal to moose (Telfer 1970a, Anderson 1972, Gilbert 1973, 1974). In moose, the worms may cause severe trauma to the central nervous system, neurological disease, paralysis, and death, and may predispose moose to mortality by other causes such as hunting and accidental death due to abnormal behaviour (Benson 1958, Anderson 1964, Gilbert 1974, Thomas & Dodds 1988).

For many years, *P. tenuis* was commonly accepted as a major factor in moose population declines that seemed to be associated with increasing deer densities (Anderson 1964, 1965, 1972, Karns 1967, Telfer 1967b, 1970a, 1984, Gilbert 1973, 1974, Saunders 1973, Dodds 1974, Prescott 1974, Peek et al. 1976, Clarke & Bowyer 1986, Geist 1987, Lankester 1987, Thomas & Dodds 1988, Pulsifer 1995). More recent evidence suggests, however, that it may only be a marginal limiting factor (Telfer 1967b, 1968a, 1970a, Gilbert 1973, 1974, Kearney & Gilbert 1976, Saunders 1973, Anderson 1972, Nudds 1990, Whitlaw & Lankester 1994, Dumont & Crete 1996, Lankester & Peterson 1996). While *P. tenuis* may not be the principal cause of mortality and declining moose populations in Nova Scotia, it is likely a contributing factor that should be assessed along with food competition, habitat alteration, and other causes of mortality.

The winter tick is a common parasite in Nova Scotia and, due to very large tick loads observed on moose in the province, may also be a significant mortality factor for moose (NSDLF undated, Nette 2000). Ticks remove nutrients and blood and introduce pharmacological agents to the bloodstream which trigger increased grooming and thus premature shedding of the winter coat (Hodgdon 1961, Samuel et al. 1986, Samuel 1991). Loss of hair during the winter months can lead to thermal stress, increased metabolic demands, and hypothermia (Samuel 1991). These effects have been linked to winter nutritional stress, increased mortality, and declining moose populations in Michigan and Alberta (DelGiudice et al. 1997). Increased tick infestations seem to be associated with relatively short and mild winters; mild autumn weather allows a longer infestation period, and early spring melt produces favourable conditions for the reproduction and survival of ticks (Telfer 1984). Telfer (1984) observed these conditions in southern Alberta where a heavy tick load has been associated with increased mortality and may be limiting moose populations and distribution. Similar conditions may exist in other areas at the southern limit of moose range such as Nova Scotia.

Environmental contaminants and nutritional deficiencies have also been linked to moose disease/mortality and population declines. Elevated levels of heavy metals and trace metal imbalances due to environmental contamination may be contributing to moose mortalities in Nova Scotia (Nette 2000). Industrial pollution causes soil acidification and increased cadmium availability (Scanlon et al. 1986, Outridge et al. 1994, Selenius et al. 1996, Frank & Galgan 1997, Selenius & Frank 2000, Freedman 2001). At high levels, cadmium may have toxic effects on the central nervous and reproductive systems of moose (Scanlon et al. 1986). Outridge et al. (1994) determined that mammals are at risk when kidney cadmium concentrations exceed 30 mg/kg. Moose kidneys collected in Nova Scotia between 1998 and 2000 have shown cadmium concentrations as high as 148 mg/kg (wet weight, 7 year old animal), well beyond the level considered to be safe, and much higher than levels recorded in neighbouring jurisdictions (Nette 2000). Elevated cadmium levels may be a factor contributing to high rates of moose calf mortality in the southwestern region of the province (Nette 2000).

In areas with little buffering capability, soil acidification is associated with decreasing copper availability due to leaching (Frank et al. 1994, Frank & Galgan 1997). This may result in copper deficiency among moose, causing symptoms similar to those of *P. tenuis* including atrophy, neurological disease, impaired vision, emaciation, motor disturbances, circling, convulsions, and death (Frank et al. 1994, Selenius et al. 1996, Frank 1998). Interestingly, an increase in pH, as occurs with liming treatment to counter the effects of acidification, may also decrease the availability of copper in soil and cause copper deficiency, the effects of which are compounded by an increase in environmental molybdenum, which also results from liming (Frank et al. 1994, Frank & Galgan 1997, Frank 1998). Further investigation is required to provide conclusive evidence regarding moose mortality due to cadmium toxicity or copper deficiency in Nova Scotia (Nette 2000).

Hunting and Predation

Hunting pressure has been the cause of major moose declines in Nova Scotia and elsewhere (Dodds 1974, Bontaites & Gustafson 1993), and has been responsible for maintaining low population densities or for extirpation in some portions of traditional moose range (Telfer 1984, Wolfe 1987, Duinker et al. 1996). Due to declining populations, the hunting season was closed in 1937 in the western and central portions of mainland Nova Scotia, while some eastern counties periodically opened the hunt until 1981 (Dodds 1963, Nette 2000). Although there is currently no legal harvest of moose on the mainland, with the exception of that by First Nations, there is evidence to suggest that a few animals are illegally taken on a yearly basis, especially in the Cobequid Hills where more roads provide easier access (Nette 2000). Thus, it remains possible that poaching is among the factors affecting moose populations (Dodds 1963, Wolfe 1987, Pulsifer 1995, Chubbs & Schaeffer 1997, Nette 2000).

Although wild predators are rarely responsible for local extirpation of prey species (because to do so would be maladaptive), heavy predation in combination with other factors such as disease, severe winters, and marginal range may limit populations and perhaps cause declines and extirpation (Telfer 1984). It has often been assumed that due to the absence of wolves, predation has had little effect on moose populations in Nova Scotia (NSDLF undated, Benson 1957, Dodds 1974). However, it has been recently recognized that black bear predation can be a significant calf mortality factor, and can potentially restrict populations in areas of low population density (Wright 1956, Messier & Crete 1984, Franzmann & Schwartz 1986, Fowler 1987, Karns 1987, Larsen et al. 1989, McNicol 1990, van Ballenberghe & Ballard 1994, Bontaites & Gustafson 1993, Pulsifer 1995, Stenhouse 1995, Chubbs & Schaeffer 1997). Low-density moose populations are sympatric with stable black bear populations throughout their range in Nova Scotia (Nette 2000); thus, black bear predation of calves may be a potentially significant limiting factor.

Population Viability

Natural populations are subject to stochastic and deterministic factors which influence birth and death rates and lead to fluctuations in population size. Small, isolated populations are especially vulnerable to extinction in the face of demographic, genetic and environmental changes (Diamond 1976, Terborgh & Winter 1980, Shaffer 1981, Newmark 1985, Samson et al. 1985, Gilpin & Soulé 1986, Gilpin 1991, Henriksen 1997). Population viability assessment (PVA) has become a popular tool in wildlife conservation, and is used to determine the minimum viable population size (MVP) (Shaffer 1990, Boyce 1992, Theberge 1993, Lacy 1993/94, Reed et al. 1986, 1998). MVP represents the population size below which the probability of extinction is unacceptably high, but at or above which the probability of extinction is reduced to an acceptable level over a given time period (Samson 1983, Gilpin & Soulé 1986, Lacy 1993/94, Henriksen 1997). To obtain a useful and reliable prediction of MVP through PVA, detailed information is required on species demography, ecology, genetics, and habitat relationships, as well as local environmental conditions and variability. In many cases, these data are not available; however, some general rules have been developed based primarily on genetic considerations and are supported by empirical and experimental evidence (Franklin 1980, Soulé 1980, Shaffer 1981, 1983, Brussard 1985, Samson et al. 1985, Lande 1987, Berger 1990, Thomas 1990, Henricksen 1997). For short-term viability (a few decades), a minimum effective population of 50 individuals is required to avoid inbreeding depression; however, to avoid the long-term (centuries) loss of genetic variability through drift, a population should include at least 500, or even 5000, individuals. Furthermore, these estimates only refer to the genetically effective population (N_e) which represents the number of randomly breeding individuals, and is often much lower than the actual census population (N) (Franklin 1980, Brussard 1985, Newmark 1985, Samson et al. 1985, Henriksen 1997).

Preliminary MVP figures have been calculated for moose in mainland Nova Scotia (Beazley 1998, Snaith 2001). Because the information required for a reliable PVA is unavailable, these figures are estimates based on the general assumption that 500 breeding individuals are enough to ensure long-term viability (Franklin 1980). A ten-to-one relationship between N and N_e was applied based on calculations made for moose elsewhere (Ryman et al. 1981, Arsenault 2000). Using this 10% relationship, it follows that for an effective population size of 500 moose, an actual minimum viable census population of 5000 individuals is required to ensure long-term persistence. The current population of 1000 moose, fragmented among a number of smaller and isolated populations, is not enough to ensure the persistence of moose over the long term (Snaith 2001, Snaith & Beazley 2003).

In order to address conservation problems, MVP requires spatial application; in other words, the amount of habitat required to support the MVP must be calculated. The minimum critical area (MCA) represents the minimum amount of suitable habitat required to support the population, and is calculated based on the number of individuals and their area requirements or population density (Soulé 1980, Shaffer 1981, Lehmkhul 1984, Newmark 1985, Metzgar & Bader 1992, Theberge 1993, Doncaster et al. 1996, Arsenault 2000).

For moose in Nova Scotia, MCA can be calculated using the MVP size, multiplied by the area requirements (home range size) of each individual or by dividing MVP by the average regional population density (Shaffer 1981, Newmark 1985, Theberge 1993, Doncaster et al. 1996, Beazley 1997, 1998, Snaith 2001). Based on local average home range sizes (30-55 km^2) and density (0.05/km^2), MCA for long term viability was calculated as 100 000 to 200 000 km^2 (Snaith 2001, Snaith and Beazley 2003). The total area of mainland Nova Scotia is about 45 000 km^2. Clearly, if these calculations are correct, Nova Scotia is not large enough on its own to maintain a viable moose population over the long term. Connectivity among local moose populations and to those in New Brunswick is essential for the maintenance of moose in Nova Scotia.

Conclusion

Mainland Nova Scotia moose populations have been considerably reduced from pre-Euro-American contact levels and may currently be declining due to a number of factors including habitat conversion, degradation, and fragmentation, interspecific competition, disease, environmental contamination, predation, and poaching. Although the causes of the decline of moose in Nova Scotia remain ambiguous, it is clear that the population has dropped to levels low enough to place them at risk. Because Nova Scotia moose populations are small and isolated, they are particularly susceptible to further reductions through genetic, demographic, or environmental fluctuations.

Currently, the Nova Scotia mainland does not support a moose population large enough to persist for the long term, nor does it contain enough area to support such a population in isolation. In order to ensure the persistence of moose in Nova Scotia, conservation efforts should concentrate on the following:

i. maintaining and enhancing all seasonally critical habitat elements (including forage, thermal and escape cover, calving areas, winter yards, and water bodies) in and around areas where moose currently exist;
ii. designing forestry management strategies to maintain and enhance sufficient thermal cover and interspersion of habitat elements;
iii. increasing understanding, through empirical research, of potential population limiting/regulating factors;
iv. reestablishing habitat connectivity for dispersal/migration between the two mainland populations to allow genetic exchange which will increase the effective population size;

v. restoring the critical habitat area and components required to support an increase in the population to long-term MVP level: habitat restoration should aim to improve the quantity of habitat (to support more individuals on a larger area) and the quality of habitat (to support a larger population on the same area at higher densities); and,

vi. reestablishing habitat connectivity with New Brunswick to allow dispersal and migration to increase gene flow and to further increase effective population size over the long term; this will also allow opportunities for responses to climate change.

In light of the information presented in the literature, as well as what is known about moose in mainland Nova Scotia, further attention to their distibution, status and habitat associations is warranted.

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Appendix 1 **Critical Habitat Components**

Source	Site	General	Summer (Spring/Fall)	Winter	Special Components
NSDLF undated	Nova Scotia		Aquatics		Salt licks spring
Telfer 1967a	Nova Scotia - Cobequids			Winter yards on upper SW facing slopes. Have patches of dense mature forest critical for shelter and open areas (20 years old cut) with good forage	
Telfer 1967b	Nova Scotia - Cobequids			Winter yards with dense softwood for cover and open areas with diverse species for food	
Prescott 1968	Nova Scotia - N. mainland			Concentrate in areas with diverse vegetation types for combination of food and shelter. Like high elevation, usually boundary of softwood and hardwood forests	
Wright 1956	New Brunswick	Secondary vegetation from disturbances such as fire, insect outbreaks, blowdowns - good after a few years, peak after 40y. Aquatics	Aquatics	Diverse tree species	Mineral licks

Appendix 1 cont'd

Source	Site	General	Summer (Spring/Fall)	Winter	Special Components
Telfer 1968a	New Brunswick	Cover adjacent to food areas	Forage rich areas and shelter providing dense forest	Early winter -dense hardwoods and open softwood food producing areas. Late winter shelter is critical - use dense softwood or dense cover mixedwood stands with little browse availability so edges of adjacent food areas also used	
Telfer 1970a	New Brunswick			Early winter deciduous cover and open areas for food Late winter dense conifer for cover related to snow depth	
Leptich & Gilbert 1989	Maine		Aquatic vegetation and cutover areas		
Crossley & Gilbert 1983	Maine		Lowland areas, aquatic areas, Cedar stands for cover	Upland areas	
Leptich & Gilbert	Maine				Calving sites - 1986 secluded, undisturbed, forested, near water, browse availability
Dunn 1976	Maine		Aquatic feeding and ponds for heat stress Softwood cover and mixed forest		

Thompson et al. 1995	Maine		Aquatics and mature hardwood and mixedwood stands	Mature conifer stands for cover. 10 - 30 year old cutovers for forage (with residual cover)	
Bontaites & Gustafson 1993	New Hampshire		Males - mature hardwood in summer, clearcuts in fall Females - clearcuts and wetlands in summer mature hardwoods in fall	Mixed wood stands	Salt licks - most animals will elongate HR to include
Banfield 1974	Canada		Higher altitudes Aquatic vegetation	River edges Valleys Shrubby open woodland	
Kelsall 1987	North America review article				
Jordan 1987	Review article		Aquatic food is an important source of sodium		
Albright & Keith 1987	Newfound-land		Open barrens	Wooded sites with mature conifers but little food. Cover is critical in severe winters.	
Crete & Jordan 1982	Quebec			Late winter closed canopy	
Joyal & Scherrer 1978	Quebec		Aquatic vegetation		
Joyal 1987	Quebec	Disturbances increase browse production	Ponds and bogs with aquatic food	Mixed forests with conifer cover	
Brassard et al. 1974	Quebec	Diversity, interspersion, early succession			

Appendix 1 cont'd

Source	Site	General	Summer (Spring/Fall)	Winter	Special Components
Kearney & Gilbert 1976	Ontario		Waterways and beaver ponds Open areas with forage Late summer taller forest for thermal cover	Forage is important	
Forbes & Theberge 1993	Ontario			Local scale: critical winter cover closed canopy conifer forest Regional scale: disturbance 33% of area for browse availability	
deVos 1958	Ontario		Aquatic veg important all summer June to October		
Puttock et al. 1996	Ontario		Aquatics. Early succ. tree species for high quality forage Disturbed open areas Mature mixed forests	Mature stands Cover near forage Conifer-dominated stands with dense canopies 1-20 years old stands with <30% stocking Conifer stands >20yo with <50% canopy closure Avoid open areas	Calving sites: islands, peninsulas, elevated locations
Thompson & Vukelich 1981	Ontario			Cover is critical, stay within 12m of cover	
Thompson & Euler 1987	Ontario	Coniferous cover for thermal stress and escape	Early successional habitat for food Aquatic feeding sites for sodium	Mature stands of coniferous cover Yarding areas	Calving sites Mineral licks

McNicol & Gilbert 1987	Ontario	Mature forests continually produce moose habitat through natural disturbances such as fire, disease, and blowdowns.			
Allen et al. 1987	Lake Superior region (HSI modeling)	Habitat interspersion and species diversity	Wetlands with aquatic forage rich in sodium Mature dense conifer cover for heat stress Early succ. veg for forage	Cover is critical - dense conifer or mixed stands Early succ. veg for forage Mosaic of shelter and food. In very deep snow will select for cover even if no food	Mineral licks Calving sites - isolated, near water, dense vegetation
Peek 1974b	W. North America			Riparian areas and willows	
Hauge & Keith 1981	Alberta		Spring - open lowlands are critical Summer - open uplands	Early winter- lowlands Late winter - forested uplands	
Mytton & Keith 1981	Alberta	Avoid human disturbance	Open areas, aspen islands, muskegs	Tall, dense forest	
Quinlan et al. 1990	Alberta	Scattered coniferous shelter interspersed with browse-producing areas			
Eastman 1974	British Columbia	Forests and small scale disturbances	Selectively logged areas for forage	Burns and partial cutovers for forage in early winter. Forests for shelter in late winter	
Eastman & Ritcey 1987	British Columbia	Early serial stages Riparian habitat	Cover from heat stress Forage in open areas at higher elevations Aquatic vegetation	Cover, especially in areas with deep snow	Calving sites

Appendix 1 cont'd

Source	Site	General	Summer (Spring/Fall)	Winter	Special Components
Demarchi & Bunnell 1995	British Columbia		Summer thermal cover very important for weight gain and winter survival		
Schwab 1985	British Columbia		Spring - open for forage Summer - closed forest for heat stress	Early winter - open for forage Mid/Late winter - heavy forest cover	
Sumanik & Demarchi 1977	British Columbia			Riparian habitat have food, cover and less snow for easy travel	
Bowyer et al. 1999	Alaska				Calving sites with high quality forage and good cover for predator protection
Collins & Helm 1997	Alaska		Early succ. habitat	Early shrub for forage Old poplar for browse and cover	
Doerr 1983	Alaska	Clearcut forests and riparian habitat		High volume old growth conifer forest Riparian shrub	
Miquelle et al. 1992	Alaska	Willows heavily used for forage	Females select cover for predator protection Males select open areas for browse	Forest thermal cover critical especially for females	Forested calving sites

MacCracken et al. 1997	Alaska	Landscape scale select for forage availability cover HR scale select for cover and forage or primarily	Aquatic plants		
Taylor & Ballard 1979	Alaska	Spruce dominated forest interspersed with willows or scrub birch		Valley bottoms are winter concentration areas	Forested spruce dominated calving sites
Oldemeyer & Regelin 1987	Alaska	Prefer early succ. stages. Mature forest and river valleys can support small pops.			
Krefting 1974	NC North America		Disturbed areas with early seral vegetation	Conifer cover	
Ackerman 1987	Michigan		Mature forest cover from heat stress Water bodies		
Peek et al. 1987	Idaho		Variability in cover types Occasional use of lakes and ponds	Old growth, double canopy conifer stands with understory shrubs Riparian zones	
Pierce & Peek 1984	Idaho	Select habitat for abundant forage Old growth important	Even aged pole timber stands and open areas including clearcuts	Dense old growth stands are critical for cover and forage	
Peek et al. 1976	Minnesota		Aquatics Sparsely stocked forest stands	Dense conifer cover from deep snow	
van Ballenberghe & Peek 1971	Minnesota		Swampy and upland forest Aquatic feeding sites	Dense habitat during rapid snow accumulation	

Appendix 1 cont'd

Source	Site	General	Summer (Spring/Fall)	Winter	Special Components
Phillips et al. 1973	Minnesota		Low open habitat provides first green vegetation. Not much use of aquatics	Dense aspen cover from snow depth	
Berg & Phillips 1974	Minnesota	Willows are an important food species	Low willow habitat	Tall willows and deciduous and coniferous forests. Need for cover correlated with snow depth	
Knowlton 1960	Montana	Prefer uplands >7500 ft.	Higher elevations with green up Subalpine meadows and willow bottoms Coniferous forest for rest and escape cover	Forced to lowlands due to snow depth Winter concentrations in willow bottoms along waterways Coniferous forest for snow cover	
Houston 1968	Wyoming	Dense willow important year round Climax conifer forest has cover and food Floodplain forest veg	Grasslands with forbes and grasses important spring and early winter	Spruce/fir and floodplain forest	
Towry 1984	Colorado	Willows Aquatic plants, upland shrubs, forbes and grasses			Calving sites - thickets, dense vegetation near openings and
water					

Bobek & Morow 1987	Poland	Forest cutting creates browse production		
Cederlund & Markgren 1987	Sweden	Young deciduous vegetation and Scots Pine are most important moose foods in Europe		Young pine forests have good quality winter browse
Cederlund & Okarma 1988	Sweden	Clearcuts, young and medium aged forests preferred Avoid mature stands and bogs		
Strandgaard 1982	Sweden			Dense forest edges for cover Open areas 0-40 years old for forage Old forest 40-60 years old for cover and forage
Hjeljord et al. 1990	Norway	Diversity of habitat and food types		
Heikkila et al. 1996	Finland	Forested peatlands	Old and middle aged forests with lots of undergrowth and edge	Closed forest

Appendix 2 Moose Food Preferences by Species

Source	Site	Food Species
Benson 1957	Nova Scotia	**Winter:** Fir (Abies spp.) White birch (Betula papyrifera) Yellow birch (Betula alleghaniensis) Beaked hazelnut (Corylus cornuta) Maples (Acer sp.) **Available but not eaten:** Spruce (Picea sp.) Wire birch (Betula sp.) Beech (Fagus grandifolia)
Prescott 1968	Nova Scotia N. mainland	Mountain maple (Acer spicatum) (25.5% of diet; 15.9% of available food) Yellow birch (Betula lutea) (19.9%; 9.5%) Sugar maple (Acer saccharum) (16.5%; 15%) Balsam fir (Abies balsamea) (13.6%; 16.2%) Red maple (Acer rubrum) (8.5%; 6.4%) Hazel (Corylus cornuta) (6.1%; 2.5%) Elderberry (Sambucus pubens) (1.4%; 2.2%) Striped maple (Acer pensylvanicum) (1.4%; 0.9%) White birch (Betula papyrifera) (1.2%, 2.1%) Honeysuckle (Lonicera canadensis) (1.1%; 6.8%) Beech (Fagus grandifolia) (0.9%; 1.6%) Blackberry (Rubus allegheniensis) (0.7%; 0.6%) Hobblebush (Viburnum alnifolium) (0.6%; 0.2%) Cornus spp. (Cornum spp.) (0.6%; 0.8%) Raspberry (Rubus stringosus) (0.6%; 12.2%) Cherry (Prunus pensylvanica) (0.5%; 1.8%) Willow (Salix spp.) (0.5; 0.1) imp. at low elev. Ribes spp. (Ribes spp.) (0.1%; 2.3%) **Available but not eaten:** Red spruce (Picea rubens) White ash (Fraxinus americana) Yew (Taxus canadensis) Mountain Ash (Sorbus americana) Speckled Alder (Alnus rugosa) Blueberry (Vaccinium myrtilloides) White spruce (Picea glauca) Rose sp. (Rosa sp.)
Telfer 1967a	Nova Scotia Cobequids	**Winter concentration areas:** Balsam fir (Abies balsamea) White birch (Betula papyrifera) Yellow birch (Betula alleghaniensis) Sugar maple (Acer saccharum)
Telfer 1967b	Nova Scotia Cobequids	**Winter** Maples (Acer rubrum, A. saccharum, A. spicatum) (50% of diet) Yellow birch (Betula alleghaniensis) (18%) Balsam fir (Abies balsamea) (small amount)

Appendix 2 cont'd

Source	Site	Food Species
		Abundant but not eaten
		Raspberry (Rubus strigosus)
Basquille & Thompson 1997	Nova Scotia Cape Breton Highlands	**Ordered by preference index**
		White birch (Betula papyrifera)
		Balsam fir (Abies balsamea)
		Mountain ash (Sorbus americana)
		Shadbush (Amelanchier sp.)
		Sugar maple (Acer saccharum)
		Striped maple (Acer pensylvanicum)
		Red maple (Acer rubrum)
		Speckled alder (Alnus rugosa)
		Mountain maple (Acer spicatum)
		Elderberry (Sambucus pubens)
		White ash (Fraxinus americana)
		Beech (Fagus grandifolia)
		Pin cherry (Prunus pensylvanica)
		Balsam poplar (Populus balsamifera)
		White pine (Pinus monticola)
		Wild raisin (Viburnum cassinoides)
		Ironwood (Ostrya virginiana)
		White spruce (Picea glauca)
		Black spruce (Picea mariana)
		Currant (Ribes sp.)
		Hemlock (Tsuga sp.)
		Larch (Larix sp.)
		Yellow birch (Betula alleghaniensis)
		White elm (Ulmus americana)
		Red Oak (Quercus rubra)
		Jack pine (Pinus banksiana)
		Trembling aspen (Populus tremuloides)
Telfer 1968a	New Brunswick	**Early winter:**
		Red maple (Acer rubrum)
		Wild raisin (Viburnum cassinoides)
		Striped maple (Acer pensylvanicum)
		Beaked hazel (Corylus cornuta)
		Mountain maple (Acer spicatum)
		Sugar maple (Acer saccharum)
Wright 1956	New Brunswick	**Winter: Heavy use:**
		Gray birch (Betula populifolia)
		Yellow birch (Betula alleghaniensis)
		White birch (Betula papyrifera)
		Red maple (Acer rubrum)
		Striped maple (Acer pensylvanicum)
		Willow (Salix sp.)
		Aspen (Populus sp.)
		White cedar (Thuja sp.)
		Viburnum (Viburnum sp.)
		Cherry (Prunus sp.)
		Hard maple (Acer sp.)

Appendix 2 cont'd

Source	Site	Food Species
		Leatherleaf (Chamaedaphne calyculata) **Slight/moderate use:** Balsam fir (Abies balsamea) Alder (Alnus sp.) White pine (Pinus monticola) Raspberry (Rubus sp.) Silver maple (Acer saccharinum) Hazel (Corylus cornuta) Oak (Quercus sp.) **Present but NOT eaten:** White spruce (Picea glauca) Black spruce (Picea mariana) Tamarack (Larix laricina) Hemlock (Tsuga sp.) Beech (Fagus grandifolia) Shadbush (Amelanchier sp.)
Crete 1987	Quebec Gaspe Peninsula	**Winter:** White birch (Betula papyrifera) (49% of diet; 7% of available biomass) Balsam fir (Abies balsamea) (19%; 88%) Mountain maple (Acer spicatum) (10%; 1%) Amelanchier (Amelanchier sp.) (9%; 2%) Red-osier dogwood (Cornus stolonifera) (6%; 1%) Cranberrybush (Viburnum edule) (3%; 1%) Willow (Salix sp.) (2%; <1%) Mountain ash (Sorbus americana) (1%; <1%) Alder (Alnus crispa) (1%; <1%) Quaking aspen (Populus tremuloides) (<1%; <1%) Pin cherry (Prunus pensylvanica) (<1%; <1%)
Raymond et al. 1996	Maine	Paper birch (Betula papyrifera) Pin cherry (Prunus pensylvanica) Aspen (Populus tremuloides and P. grandidentata) Red maple (Acer rubrum) Yellow birch (Betula alleghaniensis) Striped maple (Acer pensylvanicum) Sugar maple (Acer saccharum) Mountain maple (Acer spicatum) Willow (Salix sp.) Mountain ash (Sorbus americana) Balsam fir (Abies balsamea)
Crossley & Gilbert 1983	Maine	**Winter:** Balsam fir (Abies balsamea) Quaking aspen (Populus tremuloides) Paper birch (Betula papyrifera)
Telfer 1984	Atlantic Canada and New England	Mountain maple (Acer spicatum) Striped maple (A. pensylvanicum) Wild raisin (Viburnum cassinoides) Witch Hazel (Hammalis virginiana)

Appendix 2 cont'd

Source	Site	Food Species
		Blueberry (Vaccinium sp.) Fir (Abies sp.) Birch (Betula sp.) Aspen (Populus sp.)
Banfield 1974	Canada	**Winter:** Willows (Salix spp.) Balsam fir (Abies balsamea) Red-osier dogwood (Cornus stolonifera) Mountain ash (Sorbus americana) Aspen (Populus grandidentata) Birch (Betula spp.) Beaked Hazel (Corylus cornuta) Balsam (Abies balsamea) Poplar (Populus balsamifera) Pin Cherry (Prunus pensylvanica) Maple (Acer spp.) Viburnum (Viburnum spp.)

Some species/common names from Rowe (1972)

Appendix 3 Forestry and Management Recommendations

Source	Site	Forestry and Management
Prescott 1968	Nova Scotia - N. mainland	Small scale disturbances like selective cutting are beneficial to moose because openings produce browse while maintaining enough cover. Bigger clearcuts not good because regeneration is poor, edges of remaining cover sustain wind damage, monoculture regeneration is no good.
Telfer 1968a	New Brunswick	Cuttings adjacent to winter shelter will provide winter food. Moose will not make use of forage in large open areas. Need detailed local information on moose habitat selection and ranging patterns.
Telfer 1970b	New Brunswick	60-80% of an area should be >35 years old at all times. Need information on moose distribution and key habitat areas for consideration in forest management operations. Clearcut patches or strips <100 feet wide and arranged to ensure adequate cover remains near forage production areas.
Kelsall 1987	North America	review article Some management can improve habitat and allow expansion of moose range.
Joyal 1987	Quebec	Logging provides short term benefit of increased browse production, peaks 5-15 y after cut. Leave ten 2-3 ha stands per 10 km^2 . Consider suitability of planted species. Large clearcutting reduces habitat, and if few small clumps of cover left behind, moose are trapped and vulnerable and must compete for small remaining areas.
Brassard et al. 1974	Quebec	Logging provides only short term benefits of early successional forage. Production of monocultures is poor moose habitat.
Thompson et al. 1995	Maine	Moose will use cuts 10 to 30 years old for forage only if residual softwood stands remain for cover
Hogg 1990	Ontario	Large cuts >100ha must include shelter patches of 3-8ha or be shaped so never more than 200m to cover. Harvesting and access roads located with care to avoid critical habitat components such as calving areas and aquatic feeding sites.
Thompson & Vukelich 1981	Ontario	Moose use cuts after 18y post cut Cows with calves rarely more than 60m from cover

Appendix 3 cont'd

Source	**Site**	**Food Species**
Thompson & Euler 1987	Ontario	Large clearcuts with successional vegetation not as useful as small ones Must leave some uncut areas
McNicol & Gilbert 1987	Ontario	Irregular shaped cuts Scattered shelter patches Stands with diverse age/ species composition
Hamilton et al. 1980	N. Ontario	Use of clearcuts restricted to areas within 80m of cover
Allen et al. 1987	Lake Superior region	(HSI modeling) Ideal year round habitat: 40-50% of area is sites with (50% shrub or young forest <20yo 5-15% conifer >20yo 35-55% deciduous or mixed forest >20yo 5-10% wetlands with aquatic foods Food within 100m of cover
Tomm & Beck 1981	Alberta	Moose use of cutblocks depends on the size of the cut, the interspersion of mature stands within the cut and levels of harassment. Prefer cuts 0.17 to 0.32 km^2 which are buffered from other openings by 200 to 400m of forest
Eastman 1974	British Columbia	Recent clearcuts least used. Partially logged stands or burns 11-20 years old are important.
Telfer 1995	Western Canada	Stand conversion to conifers with control of deciduous vegetation may limit moose numbers Uncontrolled human access may also limit numbers
Doerr 1983	Alaska	Moose use cuts <30 years post cut
Oldemeyer & Regelin 1987	Alaska	Manage large areas (2000ha management units). Intersperse undisturbed areas (40%) with disturbances.
Peek et al. 1987	Idaho	Moose did not use logged/open areas much even when available so management for early successional browse will not be effective for creating habitat. Must retain at least 55% of area in mature forest. Road closure following completion of operations.
Pierce & Peek 1984	Idaho	Avoid timber harvest in old-growth forest.
Peek et al. 1976	Minnesota	Manage township sized areas with 40-50% cutover with <20yo regeneration; 5-15% spruce/fir cover; 35-55% aspen-white birch >20y and water Cuts create browse but if plant with dense stocking or use herbicides or unfavoured species then habitat and browse decrease

Appendix 3 cont'd

Source	Site	Food Species
Houston 1968	Wyoming	Human development will cause decreasing forage availability ie. through road construction and campsite development
Cederlund & Markgren 1987	Sweden	Clearcuts can provide high quality forage.
Strandgaard 1982	Sweden	Clearcuts produce forage but pesticides decrease food availability. Older forest and dense edges also important.
Hjeljord et al. 1990	Norway older forests.	Benefit of a heterogeneous mixture of plantations and
Heikkila et al. 1996	Finland	(Managed forest) Logging areas produce patchy habitat with lots of food over a long period
Kusnetsov 1987	USSR	Cutting creates more habitat /forage and can increase population density beyond CC which becomes detrimental to habitat / forage /forest regeneration

Appendix 4 Moose Population Densities, Area Requirements, and Ranging Behaviour

Source	Site and Physical Characteristics	Population Density and Local/Seasonal Variations	Limiting/ Regulating Factors	Annual Home Range[1]	Seasonal Home Range[1]	Seasonal Range Overlap[2] and Migrations and Range Fidelity
NSDLF undated*	Nova Scotia			5.18 to 25.9 km^2 and much larger if resources are scarce		
Telfer 1968b*	Nova Scotia	High density areas: 0.46 / km^2 (Cobequids and Pictou-Antigonish highlands) Medium density: 0.05/km^2 (Tobeatic and adjacent to high density areas) Low density: 0.02				
Prescott 1968*	Nova Scotia N mainland	Ave: 0.22 / km^2 High density areas: 0.48 / km^2 >80% of population is in upland areas	Hunting - but maintaining high density population levels			
Pulsifer & Nette 1995	Nova Scotia	Cobequids: 0.01 - 0.12/ km^2 Tobeactic: 0.35 / km^2 in some areas but likely much lower in most areas				

Appendix 4 cont'd

Source	Site and Physical Characteristics	Population Density and Local/Seasonal Variations	Limiting/ Regulating Factors	Annual Home Range[1]	Seasonal Home Range[1]	Seasonal Range Overlap[2] and Migrations and Range Fidelity
Pulsifer 1995	Nova Scotia	Mainland 1995: 0.08 / km^2 1969s: 0.46 / km^2 Cape Breton 1995: 1 to 2.8 / km^2	*P. tenuis* Deer competition Poaching Habitat fragmentation by forest management Black bear predation			
Wright 1956	New Brunswick		Deer competition may limit food availability (some overbrowsing seen in shared range)			
Crete 1987	Eastern Quebec Gaspe Peninsula	1.8 - 2.0 / km^2	No hunting Bear / wolf predation Not food limited because below calculated K. Regulated by predation	(M) 31.2 km^2 (F) 26.1 km^2		Sed
Crete 1989	Eastern Quebec Gaspe Peninsula	1.8 - 2.0 / km^2 Record high for Quebec vs. Just to north and south of study area 0.1 / km^2	No hunting Limited predation High food availability vs Hunting pressure			

Crossley & Gilbert 1983	Maine Rolling mountains with lowlands and bogs. Mosaic of vegetation			Su: 25.79 km^2 Wi: 3.37 km^2	Range fidelity Some individuals have separate seasonal ranges, others summer range is extension of winter core
Leptich & Gilbert 1989	Maine			Su: 25.2 km^2 (varies from 2 - 60 km^2)	Home range fidelity
Thompson et al. 1995	Maine			Su: 15-30 km^2 (varies from 5-126 km^2) Au: 3 km^2 Wi: 7.1 km^2 (non snow restricted year) 1.5 km^2 (snow restricted)	Seasonal ranges overlap or are within 7 km
Raymond et al. 1996	Maine Timber management area with mixture of clearcuts, partial harvests, regeneration, older second growth	1.2-1.8 / km^2			
Dunn 1976*	Northcentral Maine Mountainous with lakes, ponds and watercourses		51 km^2	Su: 18 km^2 Wi: 4.7 km^2 Au: 39 km^2	

Appendix 4 cont'd

Source	Site and Physical Characteristics	Population Density and Local/Seasonal Variations	Limiting/ Regulating Factors	Annual Home Range[1]	Seasonal Home Range[1]	Seasonal Range Overlap[2] and Migrations and Range Fidelity
Bontaites & Gustafson 1993	New Hampshire		Black bear predation Other calf mortality	M 93 km^2 F 153 km^2		
Banfield 1974*	Canada	0.77 / km^2 Winter concentrations up to 3.9 / km^2	Winter range restriction and severe food competition with deer			
Post & Stenseth 1998	North America		Direct/indirect/ cumulative effects of climate and snow depth effects predation and winter food availability			
Albright & Keith 1987	Newfoundland Barrens Poor winter range	960-1973 decline from >1.9 / km^2 to 0.8 / km^2 11973-1983 maintained at low density of 0.8 / km^2	Annual harvest Low productivity due to poor winter range/ nutrition and severe winter weather Pop maintained due to high calf survival because no predators			Distinct seasonal ranges up to 10 km apart
Chubbs & Schaefer 1997	Labrador	0.013 to 0.168 / km^2	Hunting Predation by wolves, black bears and possibly lynx.			
Brassard et al. 1974	Quebec	Large parts of Quebec <0.04 but up to >0.3/ km^2 in small areas				

Crete & Courtois 1997 (data from previous work)	Quebec-Labrador Peninsula	0.4/ km^2	Predation by wolves and bears. Low habitat productivity.			
Crete & Courtois 1997	Northern Quebec	<0.1 / km^2 study area 0.033 / km^2	Low habitat productivity limited forage availability. Also climate changes and drowning affect this low density pop without predators.	(M) 112 km^2 (F) 171 km^2	Su: (M) 67.1 km^2 Su: (F) 90.1 km^2 Wi: (M) 39.0 km^2 Wi: (F) 60.2 km^2 (M-F sig.)	7 moose: distinct seasonal ranges 8 moose: overlapping seasonal ranges
Messier & Crete 1984	Southwest Quebec	Stable at 0.37 / km^2 (equilibrium density) Lower density harvested populations 0.17-0.22/km^2	Not harvested Not food limited Wolf and bear predation - likely regulated by predation			
Joyal & Scherrer 1978	Western Quebec	0.04 / km^2				Distinct seasonal ranges
McNicol 1990	Ontario		Habitat quality affects HR size	20 to 40 km^2		
Puttock et al. 1996	Ontario -Algonquin Irregular topography, mixed forests, lakes, logging activity	1975: 0.2 to 0.3 / km 1983: 0.4 - 0.7 / km^2 1996: 0.8 / km^2	Increase associated with decline in deer.			
Thompson & Vukelich 1981	Ontario				Wi: (FC) 0.2-2.5 km^2	
Thompson & Euler 1987	Ontario	0.30 - 0.35 / km^2	Predation by wolves. Forestry may limit late winter habitat. Sodium availability.			

Appendix 4 cont'd

Source	Site and Physical Characteristics	Population Density and Local/Seasonal Variations	Limiting/ Regulating Factors	Annual Home Range[1]	Seasonal Home Range[1]	Seasonal Range Overlap[2] and Migrations and Range Fidelity
Arsenault 2000	Saskatchewan	0.29 / km^2 in good habitat 0.05 / km^2 in poorer habitat 0.07 / km^2 in poor habitat with agricultural areas				
Mytton & Keith 1981	Alberta	0.64 / km^2 in winter	No large predators No legal hunting		Su and Wi: approx 15 km^2	Mig and Sed Mig: seasonal ranges separated by (M) 13km (F) 7km
Hauge & Keith 1981	Northeast Alberta Boreal forest. Forested uplands, more open lowlands.	0.18 / km^2	Hunting. Predation by wolves.	Sed 97 km^2	Mig Su and Wi: each >20 km^2	24% Sed with overlapping seasonal ranges 76 % Mig, of these 38% distinct ranges sep. by 6km, and 62% Mig >20 km
Lynch & Morgantini 1984	Northcentral Alberta Undulating topography varied elevation and habitat in boreal environment. High degree of habitat interspersion.	0.7 to 1.6 / km^2	Food limited because widely dispersed patches. Winter browse is limited. Predation by wolf grizzly bear and black bear. Hunting		Su: (M) 22.1 km^2 Su: (F) 22.7 km^2 Su: (JM) 25.9 km^2 Su: (JF) 7.5 km^2 Su: (YM) 29.7 km^2 Su: (YF) 4.9 km^2 Au: (M) 26.1 km^2 Au: (F) 15.4 km^2	

					Au: (JM) 47.9 km^2 Au: (JF) 10.9 km^2 Wi: (M) 51.6 km^2 Wi: (F) 46.8 km^2 Sp: (M) 33.2 km^2 Sp: (F) 25.6 km^2	
Eastman & Ritcey 1987	British Columbia	0.3 / km^2 of moose range provincially. Varies from coast <0.07 / km^2 to boreal upland 0.7 / km^2				
Larsen et al. 1989	Yukon	0.19-0.25 / km^2	Some hunting Predation by grizzlies and wolves is major limiting factor preventing population increase			
Stenhouse 1995	NWT Mackenzie Valley. Low relief, northern boreal orest, a lot of early successional stage forest, also open and closed bog forest, lakes, streams and bogs	0.14 to 0.16 /km^2	Predation by wolf and grizzly bear. infer possibly limited by forage because of low pop density and large HR.	(F) 203 km^2 (40 to 942 km^2)	Au (F) 132.2 km^2 Wi (F) 57.58 km^2 Su (F) 68.35 km^2	Sed Overlap of seasonal HR.
Doerr 1983*	Southeast Alaska Varied terrain, lots of coniferous forests with productive understory	2.3 / km^2		40.3 km^2	Su: 2.1 km^2 Wi: 9.3 km^2	Mig. and Sed Sed individuals have overlapping seasonal ranges

Appendix 4 cont'd

Source	Site and Physical Characteristics	Population Density and Local/Seasonal Variations	Limiting/ Regulating Factors	Annual Home Range[1]	Seasonal Home Range[1]	Seasonal Range Overlap[2] and Migrations and Range Fidelity
Taylor & Ballard 1979	Alaska Susitna River Basin Forested mountainous terrain and tundra above timberline.			295.7 km^2 (43 to 1104 km^2)	Su: 55.7 km^2 (10 to 319 km^2)	Mig or Sed (in different areas) Mig.>150 km fidelity to migratory routes
Ballard et al. 1991	Alaska, Susitna River Basin	0.71 - 0.844 / km^2	Predation, especially brown bear but also wolf Severe winters	Mig: 505 km^2 Sed: 290 km^2	Mig Su: 263 km^2 Mig Wi: 151 km^2 Mig Au: 322 km^2 Sed Su: 103 km^2 Sed Wi: 113 km^2 Sed Au: 157 km^2	Mig and Sed. Seasonal range fidelity F philopatry M dispersal
Miquelle et al. 1992	Southcentral Alaska Denali National Park and Preserve Variable habitat, rivers and varied elevation	0.9 / km^2	Predators No hunting			
MacCracken et al. 1997	Coastal southcentral Alaska Copper River delta Delta wetlands and glacial outwash,	0.4 / km^2 (but thought to be below carrying capacity which is estimated at 0.5 - 2 / km^2) With local winter concentrations in two areas	Hunting Predation of calves by brown bears	59 ± 5 km^2	Su: 55 ± 5 km^2 Wi: 60 (7 km^2	Sed and Mig Sed: Seasonal range fidelity with >50% overlap of seasonal ranges

	highly varied habitat and shifting mosaic ie. due to river disturbance	where 90% of the population aggregates in groups of 20 -30 animals at 2.4 to 7.4 / km^2		Mig: seasonal range fidelity with <50% overlap where overlap area is used during migration (transitional zone) maximum migratory distance 25 km. Migrations related to snow conditions.
Allen et al. 1987*	Lake Superior Region (estimations for habitat modeling)	2/ km^2 is optimal habitat carrying capacity		
Ackerman 1987	Isle Royale, Michigan Island with diverse vegetation, ridges, valleys, lakes and streams	1 - 3/ km^2	No hunting	
DelGiudice et al. 1997	Isle Royal, Michigan	2.2 -3.5 / km^2	Winter ticks causing nutritional stress and hair loss causing winter mortality	

Appendix 4 cont'd

Source	Site and Physical Characteristics	Population Density and Local/Seasonal Variations	Limiting/ Regulating Factors	Annual Home Range[1]	Seasonal Home Range[1]	Seasonal Range Overlap[2] and Migrations and Range Fidelity
van Ballenberghe & Peek 1971*	Northeast Minnesota Low-relief Boreal conifer forest, lakes, mosaic of species and ages due to forestry				Su: < 2.6 km^2 core but up to 38.9 km^2 Wi: a number of cores connected by wanderings of 0.65 km to 7.8 km	In some cases, seasonal ranges are adjacent, in other cases separated by several miles.
Peek et al. 1976	Northeast Minnesota Low relief	0.43 - 1.96 / km^2				
Phillips et al. 1973*	Northwest Minnesota Varied habitat. Marsh and open water, forests, open fields, various stages of succession.	0.77 to 1.2 / km^2			Su: (AF) 17.9 km^2 Su: (AM) 14.5 km^2 Wi: (AF) 3.6 km^2 Wi: (AM) 3.1 km^2	25% Sed with overlapping seasonal HRs 15% Sed with adjacent seasonal HRs 20% Mig. 14.6 to 34 km Fidelity to migratory routes
Knowlton 1960*	Montana Gravelly Mountains Mountainous terrain. Variable habitat with forests, meadows, moist stream edges.		Hunting		Su: (AM) 2.6 km radius Su: (FC) 1.3 km radius	

Stevens 1970	Montana Gravelly Mountains	Lower than other nearby populations	Poor range conditions Low reproductive rate and low twinning rate (density dependent response to poor range)			
Peek et al. 1987	Northcentral Idaho Steep terrain. Dense Forests.	$0.9 / km^2$ abundant and productive	Some hunting.			
Houston 1968*	Wyoming $1296 km^2$ site Varied vegetation and topography with mountains, valleys, wetlands, rivers, floodplains, glacial outwash.	Wi: $0.54 / km^2$ up to $30.9 / km^2$ in localized winter habitat areas ie. flood plains. ($0.6 / km^2$ in conifer forest Su: $0.15 / km^2$ Winter has higher population density because of presence of migratory animals in study area.	Food availability (willow) as related to snow depth Competition for forage with cattle and elk. Human activities have decreased /altered habitat and reduced forage availability. Calf mortality Hunting Little effect of parasites, disease, predators.		Wi and Su (A) : 1.6 to $2.4 km^2$ Su (Y): $>4.0 km^2$ and up to $38.9 km^2$	Sed and Mig Sed: present year round in study area. 8-16 km between summer and winter ranges (some animals have completely overlapping seasonal ranges) Mig: present winter and spring. Up to 32 km between summer and winter range. Most moose have distinct seasonal ranges. Seasonal range fidelity in most cases sed and mig.

Appendix 4 cont'd

Source	Site and Physical Characteristics	Population Density and Local/Seasonal Variations	Limiting/ Regulating Factors	Annual Home Range[1]	Seasonal Home Range[1]	Seasonal Range Overlap[2] and Migrations and Range Fidelity
Bobek & Morow 1987	Poland		Hunting and Predation.			
Lehtonen 1998	Finland	1970s: 0.7 / km^2 but did damage, now managed at 0.4 / km^2	Hunting (managed population - kept under ecological K)			
Nygren 1987*	Finland	0.4 / km^2 coast 0.3 / km^2 inland 0.2 / km^2 north				
Heikkila et al. 1996*	Southern Finland Managed forest, small scale patchy mosaic.			41.54 km^2 with a 40.8 km^2 core used in all seasons	Wi: 18.88 km^2 Su: 26.57 km^2 Au: 10.17 km^2	Sed with overlapping seasonal ranges.
Cederlund & Sand 1992	Southcentral Sweden Grimso Rugged plateau, Mainly forests fragmented by logging into various successional stages, also bogs, swamps and uplands.	1.2 / km^2	Hunting removes 50% of pop annually.			Sed. Philopatric to natal HR

Cederlund & Okarma 1988	Sweden Grimso			AF 12.6 km^2 containing at least 2 core areas	AF Su 9.1 km^2 Wi 4.9 km^2	Sed with at least 10% overlap between all seasons
Cederlund & Sand 1994	Sweden Grimso			M 25.9 km^2 F 13.7 km^2 Young M/F 10 to 20 km^2	Seasonal 3 to 20 km^2	
Cederlund & Sand 1991	Sweden Grimso	1.3 / km^2	Regulated by hunting Highly productive with potential to increase numbers (lots of food, no predators, mild winters, little dispersal)			
Cederlund et al. 1987	Central Sweden	1.0 / km^2 Wi: concentr. lowlands 9 / km^2 ; uplands 0.2 / km^2 Su: uplands 1.3 / km^2 with local concentr. Of 2 to 3 / km^2	Hunting removes large numbers annually	(AF) 27.3 km^2 (0.9 to 30.3 km^2)		Primarily migratory with seasonal range fidelity
Sweanor & Sandegren 1989	Sweden	0.2 to 11.7 / km Greater in winters with less snow	Hunting 30% of pop. harvested annually	HR tended to be larger at lower density	Wi: 11.5 km^2	Migratory. Spatial fidelity to Wi HR
Cederlund & Markgren 1987	Sweden		Hunting			

Appendix 4 cont'd

Source	Site and Physical Characteristics	Population Density and Local/Seasonal Variations	Limiting/ Regulating Factors	Annual Home Range[1]	Seasonal Home Range[1]	Seasonal Range Overlap[2] and Migrations and Range Fidelity
Solberg & Saether 1999	Northern Norway - Vefsn Boreal environment, lowland forests, upland pastures.	<0.08 / km^2	Hunting. Food resources.			
Solberg et al. 1999	Northern Norway - Vefsn	0.07 to 0.79 / km^2 (pre-harvest)	Managed density dependent hunt. Climatic variation. Intrinsic variation in age structure of females in pop.			
Histol & Hjeljord 1993	Norway				Su: 9 km^2 Wi: 2.5 km^2	Mig. and Sed. All share common summer range, then some migrate up to 11 km to winter range
Syroechkovskiy & Rogacheva 1974	USSR (Asia)	0.01 to 1 / km^2 varies depending on habitat, highest in more southerly vegetated regions S. Mongolia 1 / km^2 Taiga 0.1 to 0.4 / km^2	Hunting/poaching pressure Disease			

		N. Taiga 0.02 to 0.1 / km^2 Tundra 0.01 to 0.05 / km^2	
Filonov & Zykov 1974	USSR (Europe and Urals)	0.05 to 0.67 / km^2 varies depending on habitat S. forest steppe 0.01 to 0.63 / km^2 Urals 0.05 to 0.18 / km^2 C. forest 0.13 to 0.49/ km^2 N. forest 0.18 to 0.67/ km^2 N. Taiga 0.06 to 0.18/ km^2	Hunting pressure
Kistchinski 1974	USSR (Siberia)	0.023 to 0.13 / km^2 concentrate in best habitat areas i.e. riparian brush up to 0.62 / km^2	

* Values have been converted to km^2

Abbreviations:

F	Female	Wi	Winter
M	Male	Su	Summer
A	Adult	Au	Autumn
J	Juvenile / 2 year old	Sp	Spring
Y	Yearling	Mig	Migratory
FC	Adult Female with Calf	Sed	Non-Migratory
K	Carrying capacity		

[1] Annual and seasonal home range sizes given per individual

Note: HR size per animal cannot be directly used to calculate area requirements of a population because some authors indicate that there is overlap of HR among individuals (but don't indicate degree of overlap) (Phillips et al. 1973, Doerr 1983, Cederlund & Okarma 1988, Leptich & Gilbert 1989, Cederlund & Sand 1992, Stenhouse 1995)

Note: In many cases males extended their normal range in the fall due to rutting behaviour i.e. searching for females (Knowlton 1960, Houston 1968, van Ballenberghe & Peek 1971, Phillips et al. 1973, Ballard et al. 1991).
In one case, 2 year old males displayed this pattern, presumably due to earlier maturation (Lynch & Morgantini 1984).

- Seasonal range overlap indicates that the winter and summer ranges of one individual overlap (this column does not indicate overlap among individuals).

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DEVELOPING AN INDEX OF SUSTAINABLE COLDWATER STREAMS USING FISH COMMUNITY ATTRIBUTES IN RIVER PHILIP, NOVA SCOTIA

YOICHIRO KANNO[1] and JOHN LELAND MACMILLAN[2]*
[1]School for Resource and Environmental Studies, Dalhousie University
Halifax, Nova Scotia B3H 3J5
[2]Inland Fisheries Division, Nova Scotia Department of Agriculture and Fisheries
Pictou, Nova Scotia B0K 1H0
**Current address: Embassy of Japan, Ottawa, Ontario K1N 9E6*

An Index of Sustainable Coldwater Streams (ISCS) was developed to quantify fish community changes affected by water temperature and physical habitat quality for small streams in the River Philip Watershed, Nova Scotia. The ISCS was modified from an Index of Biotic Integrity (IBI) and intended for assessing the quality of streams as coldwater habitats. The calibration of the ISCS was thought useful since global warming and habitat degradation, two major aquatic threats in the coming era, could significantly reduce the amount of undisturbed coldwater streams in Nova Scotia; thus, a tool was necessary to identify fish species vulnerable to these threats and to monitor fish community changes in relation to water temperature and physical habitat quality. There was a strong negative correlation between water temperature and physical habitat quality, and water temperature increase and habitat degradation replaced coldwater fish assemblages dominated by salmonids with warmwater and/or tolerant fish assemblages, coupled with increased total species richness. The proposed ISCS is composed of five metrics: (1) number of fish species, (2) percent of individuals that are salmonids, (3) percent of individuals that are brook trout (*Salvelinus fontinalis*), (4) percent of individuals that are white sucker (*Catostomus commersoni*), and (5) percent of individuals that are catchable salmonids (age 2 years and older). The ISCS is a promising index to identify priority conservation areas and to monitor changes in aquatic environments.

Dans le but de quantifier les changements dans les communautés de poissons touchées par la température de l'eau et la qualité de l'habitat physique pour les petits cours d'eau du bassin hydrographique de la rivière Philip, en Nouvelle-Écosse, on a élaboré un indice de qualité des petits cours d'eau comme habitats d'eaux froides (Index of Sustainable Coldwater Streams, ISCS). Cet indice, inspiré d'un indice de l'intégrité biotique (Karr, 1981; Lyons *et al.*, 1996), vise à évaluer la qualité des ruisseaux en tant qu'habitats d'eaux froides. On a pensé qu'il serait utile de calibrer l'ISCS, compte tenu du réchauffement de la planète et de la dégradation de l'habitat, deux menaces importantes pour les milieux aquatiques qui pourraient réduire considérablement le nombre de ruisseaux d'eaux froides non perturbés en Nouvelle-Écosse; c'est pourquoi il fallait un outil pour identifier les espèces de poissons vulnérables à ces menaces et pour surveiller les changements dans les communautés de poissons en rapport avec la température de l'eau et la qualité de l'habitat physique. On a observé une forte corrélation négative entre la température de l'eau et la qualité de l'habitat physique; de plus, l'augmentation de la température de l'eau et la dégradation de l'habitat avaient pour effet le remplacement d'assemblages de poissons d'eaux froides dominés par les salmonidés par des assemblages de poissons d'eaux tièdes ou tolérants avec une augmentation de la richesse totale en espèces. L'ISCS proposé comprend cinq paramètres : 1) le nombre d'espèces de poissons; 2) le pourcentage d'individus qui sont des salmonidés; 3) le pourcentage d'individus qui sont des ombles de fontaine (*Salvelinus fontinalis*); 4) le pourcentage d'individus qui sont des meuniers noirs (*Catostomus commersoni*) et 5) le pourcentage d'individus qui sont des salmonidés exploitables (âgés d'au moins deux ans). L'ISCS est un indice prometteur pour l'établissement de zones de conservation prioritaires et la surveillance des changements dans les milieux aquatiques.

Introduction

Human activities have caused severe loss of biodiversity in temperate freshwater fish (Miller et al. 1989, Moyle & Leidy 1992). Among various threats to aquatic fauna in North America, habitat destruction/degradation is widely regarded as the primary cause (Allan & Flecker 1993), and will likely be so in the future in light of the expected human population increase. In addition, global warming will greatly affect the distribution and survival of freshwater fish (Eaton & Scheller 1996, Keleher & Rahel 1996).

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* Author to whom correspondence should be addressed

Considering the potential negative effects of habitat destruction and global warming, it is fair to predict that current unimpaired coldwater habitats will diminish to a great extent in North America, and thus, fish species that rely on these habitats (i.e., intolerant coldwater species) will have higher risks of extirpation and extinction. The loss of coldwater resources will be a matter of great ecological, economic, and cultural concern to regions like Nova Scotia, where recreational and subsistence fisheries of coldwater fishes (i.e., salmonids) have long been enjoyed. Characterizing fish community changes in relation to physical habitat quality and water temperature would enable us to identify fish species vulnerable to habitat destruction and global warming, and to assess and monitor the state of the aquatic environment.

In this paper, we developed an Index of Sustainable Coldwater Streams (ISCS) for small headwater streams in the River Philip Watershed, Nova Scotia. The ISCS is a multi-metric index composed of fish community attributes and is modified from an Index of Biotic Integrity (IBI) (Karr 1981, Lyons et al. 1996). The objective of the ISCS calibration was to characterize fish community changes in response to habitat degradation and water temperature increase.

Materials: River Philip

River Philip, located in Cumberland County (45(50′N, 65(40′W), flows northeast into Northumberland Strait. Its drainage area is 699 km^2 with 0.25% and 0.10% being lakes and swamps, respectively (Harger 1974). River Philip extends about 34 km upstream from the head of tide at Oxford (Figure 1) (Harger 1974). The average July air temperature is 18°C, and the average January air temperature is -7°C; average total annual precipitation and snowfall are 1200-1400mm and 250-350mm, respectively (Davis & Browne 1996). Running through hilly and rural landscapes underlain by fine red sandstones, River Philip suffers relatively little from pollution (Harger 1974) and acid rain (Davis & Browne 1996).

The drainage area harbors wild populations of native salmonids (i.e., Atlantic salmon *Salmo salar* and brook trout *Salvelinus fontinalis*) and non-native brown trout *Salmo trutta* (DFO 1999, MacMillan & LeBlanc 2002). The study river today meets conservation requirements for Atlantic salmon set by the Department of Fisheries and Oceans (DFO), such as the number of returning adults (DFO 1999). The Northumberland Strait rivers are exceptional in that annual returns and escapements of Atlantic salmon have been generally unchanged since 1984, while all other areas in the province have seen moderate to significant declines in salmon during the period (DFO 1999). Cumberland County is also known to support the highest species richness of freshwater fish in Nova Scotia (Gilhen 1974). Several provincially rare minnows (e.g., blacknose dace *Rhinichthys atratulus* and pearl dace *Semotilus margarita*) are reported from the County, although none is federally rare or at risk.

Methods

Data Collection

Two sets of electrofishing survey data were used to develop the ISCS in River Philip. A set of data was collected through an electrofishing survey on July 30 and July 31, 2001 (termed "base survey" hereafter). The summer low-flow period was selected because it maximized sampling efficiency and reduced danger for samplers (USEPA 1997). Through preliminary field trips, 10 sites had been selected for sampling (Fig 1). These sites were similarly small in size, and stream orders ranged between 1 and 3 on a 1:50,000 topographic map (Table 1). These streams were different in natural features and the levels of anthropogenic disturbances. In general, forested and hilly headwater areas, south of Collingwood Corner, are the least impacted portions of the watershed (Fig 1). Moving northward in a downstream direction, shorter trees and grasses start to predominate the landscape and the intensity of human activities also increases. Urbanization is evident near the town of Oxford, and site 10 is apparently the most impacted site in the base survey (Fig 1). Despite the noticeable differences among the

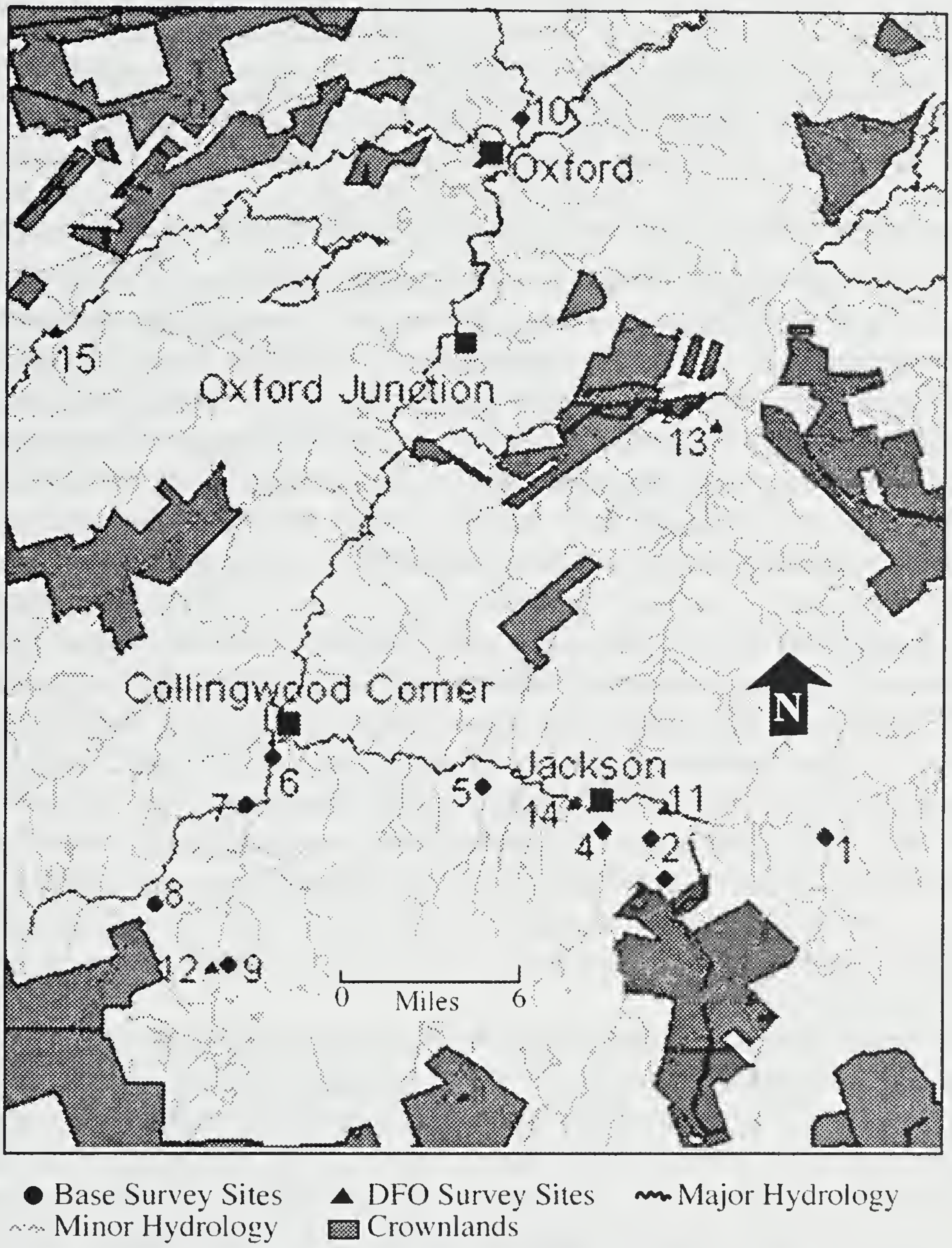

Figure 1 Survey sites in River Philip (map from Nova Scotia Geomatics Centre, Amherst, NS).

10 sites in the base survey, all the sites would be expected to be capable of supporting coldwater fish communities in the absence of human activities, although upstream portions in the watershed are probably more suitable coldwater sites than downstream areas due to their naturally colder water temperature.

Table 1 Selected physical characteristics of the 10 sites in the base survey.

	Site 1	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 7**	**Site 8**	**Site 9**	**Site 10**
Sampled length	60m	60m	50m	50m	50m	60m	70m	50m	60m	60m
Mean width	4.1m	3.7m	6.4m	5.6m	3.7m	3.5m	4.1m	6.4m	4.5m	4.9m
Mean depth	14cm	20cm	41cm	17cm	11cm	14cm	19cm	21cm	27cm	21cm
Stream order	3	2	3	2	1	2	2	2	3	3

At each site of the base survey, a stream reach section of 50-70m in length was sampled using a Smith-Root incorporated model-12 backpack electrofisher. Each stream section had several riffle-pool sequences, and a single upstream pass was made without the use of barrier nets in order to obtain a representative sample of the fish community. Fish individuals captured were identified to the species level and counted in the field, and were then released to the stream alive; several minnow individuals were brought to the laboratory for identification. For the three salmonid species encountered in the base survey (i.e., brook trout, brown trout, and Atlantic salmon), the age of each individual was estimated based on the approximate body length, which was empirically determined from scales collected from salmonid populations located in tributaries of the Northumberland Strait (MacMillan, 2001). Although some overlap does exist between body lengths of different age groups, age 0+ was assigned to individuals with the fork length (FL) of less than 7cm, and age 0+ individuals were assumed to have hatched in spring of the survey year (2001). Age 1+ was assigned to those between 7cm and 12cm in FL, which were assumed to have hatched in spring of the previous year (2000). Individuals over 12cm in FL were given age >2+, and their hatching was assumed to have occurred in spring of 1999 or earlier. Following the electrofishing survey, water temperature was measured from the main stream flow, read to the closest 1°C.

Another set of fish survey data was provided by the Diadromous Fish Division of DFO (termed "DFO survey" hereafter). The DFO survey contained five sites within the study watershed (Fig 1). Its sampling period ranged from 1980 to 2000, although fish were not sampled every year during the period. One site in the DFO survey (site 12) was identical to site 9 of the base survey. Since the base survey and DFO survey employed a similar electrofishing method, results of the two surveys were considered to be comparable. Like the base survey, the DFO survey identified salmonids to species level and classified them into three age groups (i.e., age 0+, 1+, and >2+); however, minnows were often grouped as dace spp. and the exact species composition of minnows was unknown. Therefore, minnows were assembled into one group in later analysis. Water temperature data were also included in the DFO survey result. In general, the DFO survey sampled slightly wider streams than the base survey (Table 2).

Table 2 Stream sizes of the five DFO survey sites. Note that data were taken on August 11, 1986 for site 11; on August 2, 2002 for site 12; on August 8, 1980 for site 13; and on August 12, 1986 for site 14. No records were available for site 15.

	Site 11	Site 12	Site 13	Site 14	Site 15
Mean width	8.4m	4.5m	8.2m	9.5m	N/A
Mean depth	17cm	27cm	38cm	22cm	N/A
Stream order	2	3	3	4	3

Physical habitat quality was visually assessed at all ten base survey sites and at all five DFO sites, using a Habitat Assessment Field Data Sheet (high gradient streams) (USEPA 1997). The Habitat Assessment Field Data Sheet is composed of 10 habitat variables, including (1) epifaunal substrate/available cover, (2) embeddedness, (3) velocity/depth regime, (4) sediment deposition, (5) channel flow status, (6) channel alteration, (7) frequency of riffles (bends), (8) bank stability, (9) vegetative protection, and (10) riparian vegetative zone width. Each habitat variable scoring ranges from 0 (lowest habitat value) to 20 (highest habitat value). The total habitat score of a site is a sum of the 10 habitat variable scores, thus ranging from 0 (lowest habitat value) to 200 (highest habitat value). It is previously shown that natural streams provide more diverse habitats that can support native biological assemblages, and human activities typically degrade natural habitat structures and native biological communities (USEPA 1997). As such, this type of physical habitat assessment can generally assess levels of physical human disturbances.

Ecological information on fish species required to develop the ISCS (i.e., origin, general tolerance, feeding guild, habitat preference, thermal categories, and spawning types) was primarily derived from Jennings et al. (1998), Halliwell et al. (1998), and Smogor & Angermeier (1998). However, although Halliwell et al. (1998) classified all the three salmonid species found in River Philip (brook trout, brown trout, and Atlantic salmon) as "intolerant" species, we assigned "intermediate tolerance" to brown trout, considering their known tolerance of habitat degradation (Waters 1983, MacMillan & LeBlanc 2002).

Data Analysis

The ISCS was developed to value fish communities inhabiting the most unimpaired and/or the coldest streams. This premise is thought important due to the following conservation perspective. In Nova Scotia, most coldwater species, mainly the family Salmonidae, are intolerant of habitat alteration and chemical pollution, while many cool- to warm-water species, the family Cyprinidae for example, are relatively tolerant (Kanno 2002). In addition, due to their requirements for cold water temperatures, coldwater species are generally more vulnerable to global warming than warmwater species (Eaton & Scheller 1996, Keleher & Rahel 1996). So, it is fair to argue that habitat degradation and global warming would impact coldwater fish more severely than warmwater species in the province. Thus, we intended to develop the ISCS in order to assess the sustainability of coldwater streams by using the coldest and minimally impacted sites as the reference condition, and by examining the changes in fish communities as related to increasing water temperature and decreasing overall habitat quality. In this regard, the purpose of an ISCS is different from that of an IBI, which is applied to streams in a homogeneous landscape to assess biological integrity of aquatic environments (Karr 1981). Nor does the ISCS aim to assess the productivity of waters.

The calibration of the ISCS was done with a two-dimensional graphical method (Karr & Chu 1999). In this approach, qualitative values of coldwater stream quality are placed on one axis while values of each ISCS attribute tested are placed on the other axis, and the relationship between coldwater stream quality and ISCS attributes are examined visually. Therefore, this method required that sample sites first be classified into several categories of coldwater stream quality, and that appropriate ISCS metrics be selected for test.

All base survey sites and DFO survey sites were classified into three discretionary categories of coldwater stream quality based on total habitat scores calculated with the Habitat Assessment Field Data Sheet and water temperatures: 1) excellent coldwater habitats, 2) good coldwater habitats, and 3) poor coldwater habitats. Excellent coldwater habitats were defined as those having total habitat scores over 150 and water temperatures below 16°C. Good coldwater habitats failed to meet at least one of the qualifications for excellent habitats, but still possessed habitat scores over 110 and summer water temperatures below 20°C. Brook trout, the most vulnerable species to high water temperatures in River Philip (MacMillan & LeBlanc 2002), tend to avoid water temperatures above 20°C (MacMillan et al. 2004); so, waters less than 20°C are currently considered to be high-quality coldwater streams. However, we used a cut-off point of 16°C to separate excellent coldwater streams from good coldwater streams in order to account for the projected 4°C increase in water temperature in a century for the province due to global warming (Hengeveld 2000). Thus, excellent coldwater streams might still function as such after effects of global warming become prominent, while good coldwater streams are likely to become uninhabitable for brook trout, and thus less sustainable as coldwater streams. Streams with habitat scores below 110 or with summer water temperatures above 20°C, or both, were classified as poor coldwater habitats.

Originally, eighteen candidate ISCS metrics were compiled from the literature, and were thought testable in the study area (Miller et al. 1988, Mundahl & Simon 1998) (Table 3). However, only 10 of these metrics turned out to be so after the completion of data collection, due to lack of data and rarity of species on which metrics are based. So, the remaining 10 metrics were considered for further analysis.

With a two-dimensional graph, each of the 10 metrics was examined to detect whether the metric varied systematically across a gradient in the quality of coldwater habitats. Systematic changes were either constant changes along the entire gradient of coldwater quality (shown as "linear" distributions on a graph), or those that showed sudden responses in limited ranges of coldwater quality (shown as "skewed" distributions on a graph) (Karr & Chu 1999). Those metrics that showed systematic changes were then examined for redundancies because a metric that is highly correlated to another metric adds little new information (Karr et al. 1986, Kerans & Karr 1994, Mundahl & Simon 1998). Following Mundahl & Simon (1998), all possible combinations of two metrics were correlated with each other. If the Pearson correlation coefficient was 0.85 or greater in absolute values, the metric that showed less systematic changes on a graph was eliminated. The ISCS was composed of all metrics that cleared the above criteria.

Scoring thresholds of each metric included in the ISCS were also derived using a graphical method. On a graph, metric values were plotted in a rank order, and their "natural shifts and breaks" were carefully examined for cut-off points (Karr & Chu 1999). Metric values were then trisected with discretion, and we assigned scores of 10, 5, and 0 according to whether they approximate, deviate somewhat from, or deviate strongly from the values expected at the reference sites. Where applicable, the scoring

Table 3 Eighteen ISCS metrics that were originally considered to be testable in River Philip and their predicted response to environmental degradation (compiled from Miller et al. (1988) and Mundahl & Simon (1998)). Ten metrics with asterisk (*) were actually tested for the inclusion in the final ISCS.

Metrics	Predicted Response
Species richness and composition	
Number of fish species*	Increase
Number of coldwater species*	Decrease
Number of benthic species	Decrease
Number of water column species	Variable
Percent of individuals that are coldwater species	Decrease
Indicator species	
Number of intolerant species*	Decrease
Number of tolerant species	Increase
Percent of individuals that are intolerant*	Decrease
Percent of individuals that are tolerant	Increase
Percent of individuals that are salmonids*	Decrease
Percent of individuals that are brook trout*	Decrease
Percent of individual salmonids that are brook trout*	Decrease
Percent of individuals that are white sucker*	Increase
Trophic function	
Percent of individuals that are generalist feeders*	Increase
Percent of individuals that are insectivores	Decrease
Percent of individuals that are top carnivores	Decrease
Percent of individuals that are catchable salmonids (age >2+)*	Decrease
Reproductive function	
Percent of individuals that are simple lithophilic spawners	Decrease

criteria were set rather conservatively by making the range of the high value (10) proportionately smaller than its equal trisection, taking into account the fact that truly pristine areas do not exist and thus high values of 10 should be given to a relatively small number of sites.

The total ISCS score for each site was calculated by adding all metric scores. Based on the final ISCS scores of all sites, we developed narrative interpretations of sustainability as coldwater streams for five classes (excellent, good, fair, poor and very poor), by adapting those developed by Lyons et al. (1996) and Mundahl & Simon (1998).

Results

Fish Surveys

The two fish surveys contained, not surprisingly, similar species richness and relative abundance. In the base survey, a total of 735 individuals of 12 species were recorded from the 10 sites. Three salmonid species (i.e., brook trout, brown trout, and Atlantic salmon) accounted for 607 individuals (82.6%), with brown trout being the most common species in the base survey (280 individuals, 38.1%). In general, eight headwater sites (site 2 to site 9) were inhabited almost entirely by these three salmonids, and thus the species richness was low. The remaining one headwater site (site 1) also harbored the three salmonids while containing a fairly high proportion of blacknose dace (44.0%). Site 10 was exceptional in that it possessed a completely different fish assemblage. Ten species were found in this site and many of them were tolerant and/or cool- to warm-water species (e.g., white sucker *Catostomus commersoni*, common shiner *Luxilus cornutus* and blacknose dace), and brook trout and brown trout were absent. In general, sites 1-9 seemed to possess suitable abiotic conditions as coldwater streams on the basis of water temperatures and habitat quality; water temperatures ranged from 11°C to 17°C, and habitat scores were between 178 and 115 for these headwater sites. In contrast, site 10 had a much higher water temperature (24°C), and the habitat score was lowest (95).

The DFO survey recorded 8 species and one group of fish assembled as dace spp. Similar to the base survey, three salmonid species were predominant among the fish individuals captured (87.0%). However, the most abundant salmonid species in the DFO survey was Atlantic salmon (1053 individuals, 52.7%), followed by brown trout (535 individuals, 26.8%) and brook trout (150 individuals, 7.5%). This is probably because the DFO survey generally focused on wider streams than the base survey, and Atlantic salmon tends to inhabit wider and/or warmer streams than trout (Eaton et al. 1995, Bardonnet & Baglinière 2000). Judging from the base survey results and local knowledge, dace spp. should be one of the following species: blacknose dace, common shiner, golden shiner *Notemigonus crysoleucas*, creek chub *Semotilus atromaculatus*, lake chub *Couesius plumbeus*, or blacknose shiner *Notropis heterolepis*. All the species identified in the DFO survey, except sea lamprey, were also recorded in the base survey. Therefore, a total of 13 species was recorded in the two surveys (Appendix 1). The predominance of salmonids in both surveys indicates that the study area generally provides suitable habitats for coldwater species.

Development of the Index of Sustainable Coldwater Streams (ISCS)

The development of the ISCS helped to understand fish community changes in relation to water temperature and physical habitat quality. There was a significant negative correlation between water temperature and overall habitat quality (Pearson correlation r = -0.677, p-value = 0.006); this was consistent with a field observation that naturally colder upstream sites were less disturbed and possessed better physical habitat quality than warmer downstream reaches.

Of the ten metrics assessed for the ISCS inclusion (refer to Table 3), the graphical analysis indicated that two metrics did not respond to a gradient of coldwater habitat quality (number of intolerant species, percent of individuals that are intolerant) (Fig 2 and 3). These two metrics showed no distinct patterns on the graphs. Another metric showed a general, but biologically insignificant responses (number of coldwater species) (Fig 4). The number of coldwater species was generally higher in high-quality coldwater streams; however, the discrepancies were less drastic than the following seven metrics that showed systematic changes.

Seven metrics demonstrated systematic changes with the quality of coldwater streams (Fig 5-11). Two of them showed linear responses across the entire gradient of the quality of coldwater streams (number of fish, and percent individuals that are catchable salmonids) (Fig 5-6), indicating that these metrics have a wide range of sensitivity. This means that, as the quality of coldwater streams decreased, the number of fish species increased throughout and the percent of catchable salmonids individuals showed a constant decrease. The other five metrics showed skewed distributions of metric values (Fig 7-11), indicating the limited ranges where these metrics were most capable of distinguishing stream qualities. Three of them were reliable discriminators between poor coldwater streams and good coldwater streams (percent of individuals that are salmonids, percent of individuals that are white sucker, and percent of

Fig 2-11 Responses of 10 metrics tested for the ISCS inclusion. All base survey sites and DFO survey sites (including multi-year samples) were pooled for the analysis. When more than one sites share the same value on the graphs, points were slightly moved from their exact locations for better graphical presentation.

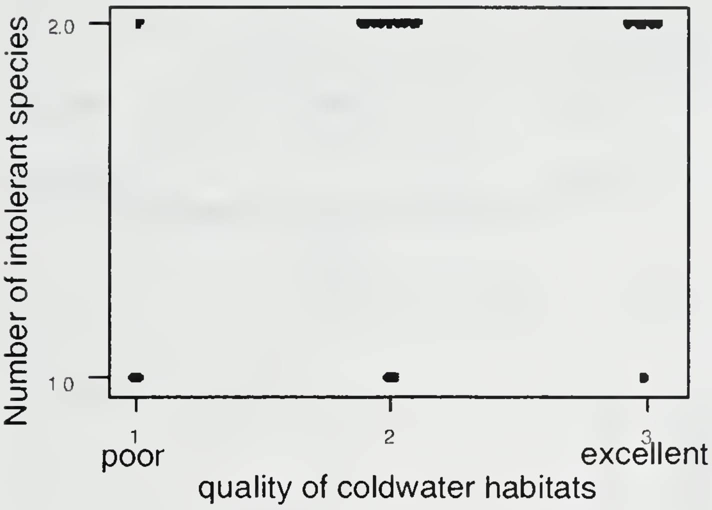

Fig 2 # intolerant species

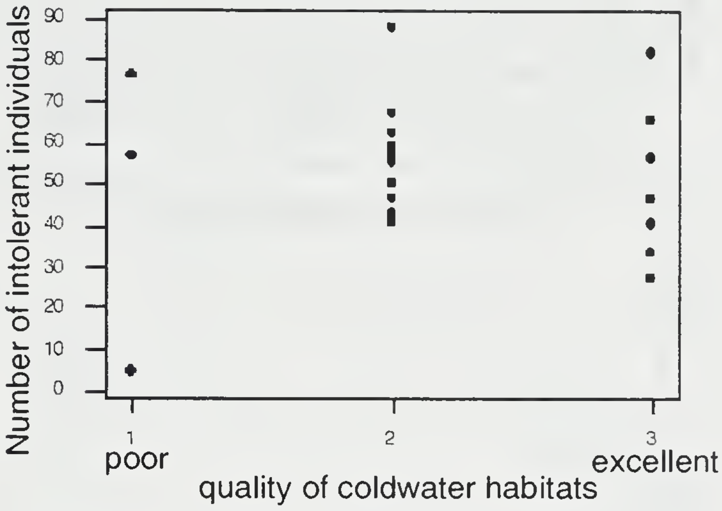

Fig 3 % intolerant species

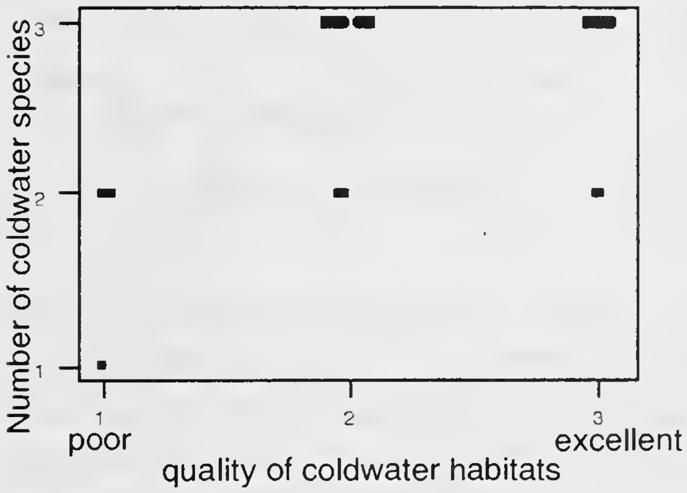

Fig 4 # coldwater species

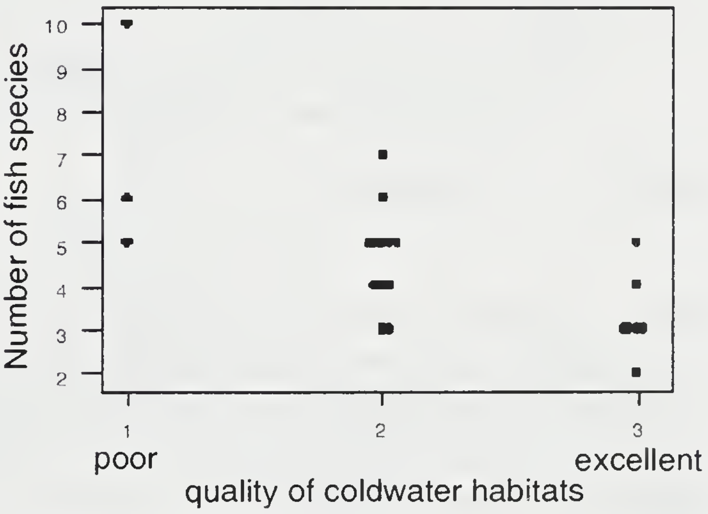

Fig 5 # fish species

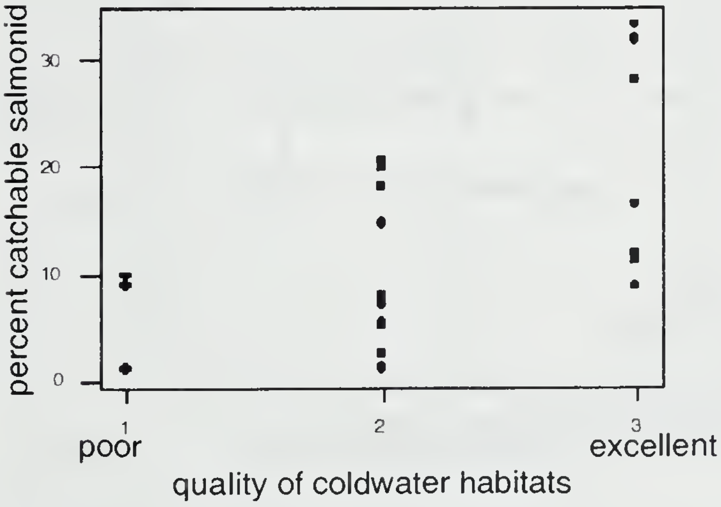

Fig 6 % catchable salmonid

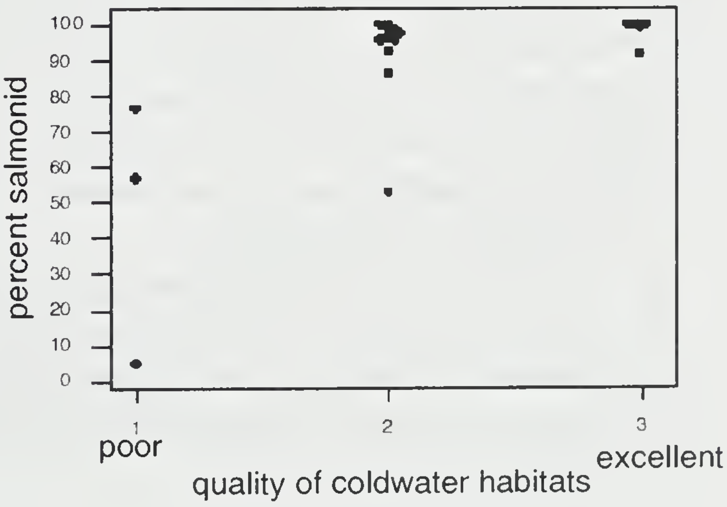

Fig 7 % salmonid

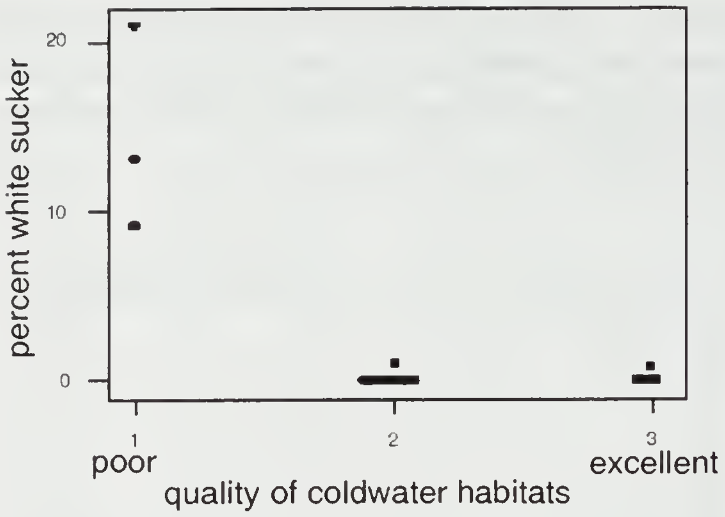

Fig 8 % white sucker

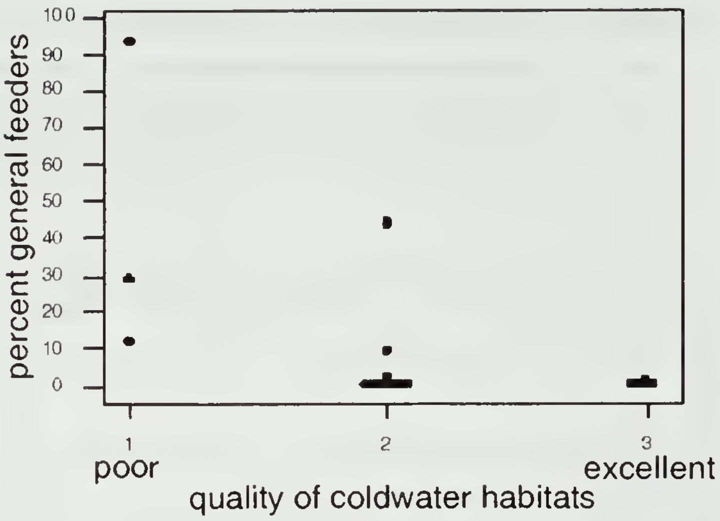

Fig 9 % general feeders

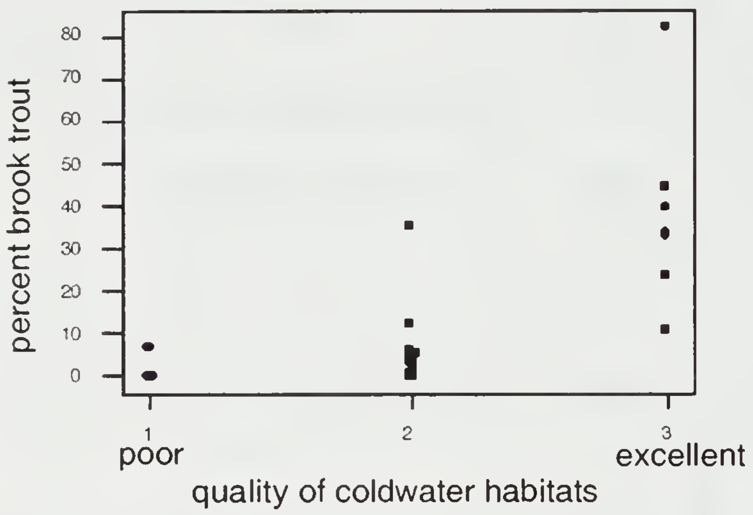

Fig 10 % brook trout

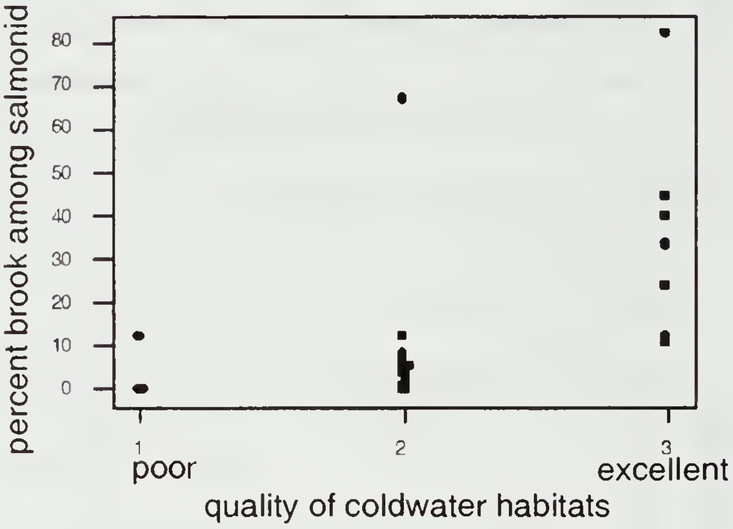

Fig 11 % brook trout among salmonids

individuals that are general feeders) (Fig 7-9). For example, the percentage of salmonid individuals (Fig 7) was relatively similar along the higher end of the coldwater quality, but sharply declined in poor coldwater streams. Finally, the last two metrics were most capable of distinguishing excellent coldwater habitats from good coldwater habitats (percent of individuals that are brook trout, and percent of individual salmonids that are brook trout) (Fig 10-11).

These seven metrics that showed systematic changes to the quality of coldwater habitats were correlated with each other. Two pairs of metrics demonstrated strong correlation (Pearson's correlation $r > 0.85$) (percent of individuals that are salmonids and percent of individuals that are general feeders; percent of individuals that are brook trout and percent of individual salmonids that are brook trout). So the metric in each pair that showed less systematic changes in the graphical analysis (refer to Fig 2-11) was eliminated, including percent of individuals that are general feeders and percent of individual salmonids that are brook trout.

As a result, the following five metrics were selected for the ISCS in River Philip:

(1) Number of fish species
(2) Percent of individuals that are salmonids
(3) Percent of individuals that are brook trout
(4) Percent of individuals that are white sucker
(5) Percent of individuals that are catchable salmonids (age >2+)

On a graph, these five metrics were visually tested for scoring criteria, and values of each metric were subjectively trisected (Figures 12-16). Due to the trisection method, each metric had a maximum score of 10, a middle score of 5, and a minimum score of 0 (Table 4). Thus, the total ISCS values ranged from 50 (the possible highest value) to 0 (the possible lowest value).

Fig 12-16 Scoring criteria for the 5 metrics included in a River Philip-ISCS. All base survey sites and DFO survey sites (including multi-year samples) were pooled for the analysis.

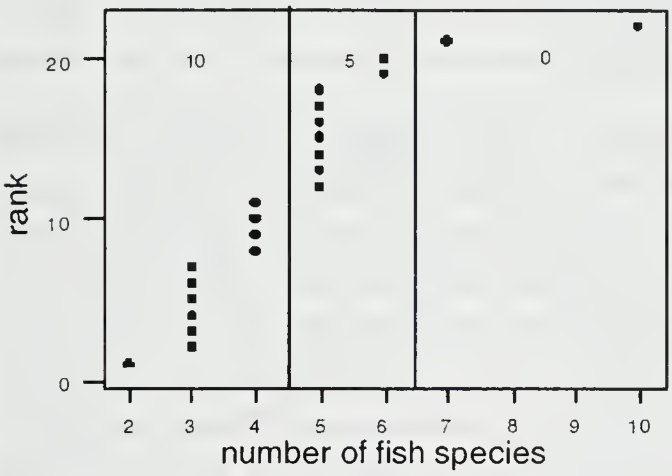

Fig 12 # fish species

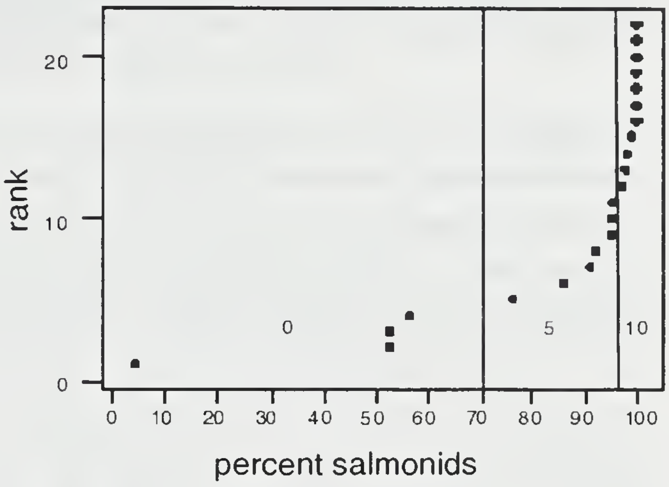

Fig 13 % salmonids

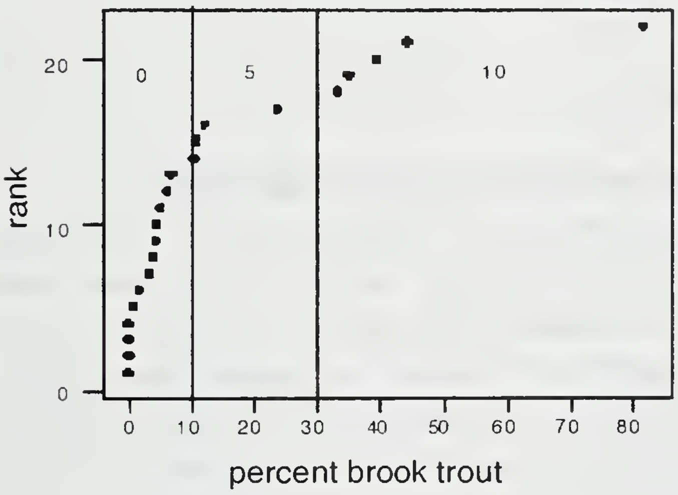

Fig 14 % brook trout

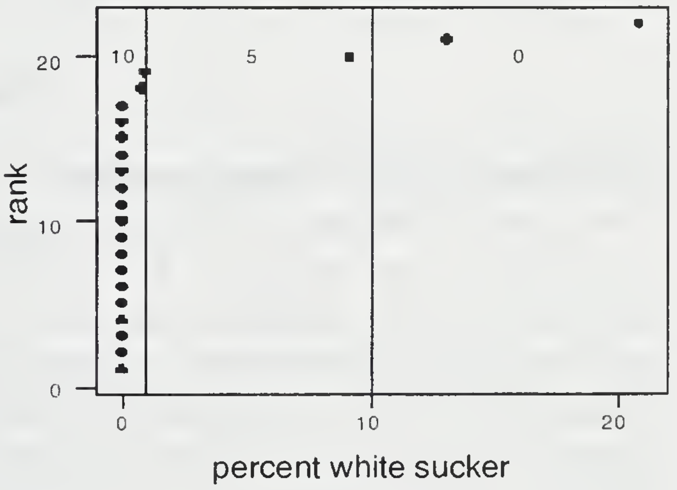

Fig 15 % white sucker

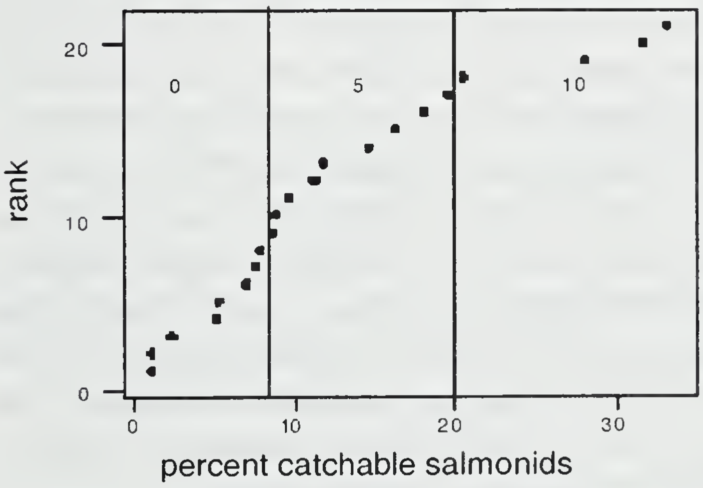

Fig 16 % catchable salmonids

Table 4 Scoring criteria for the 5 metrics included in an ISCS for River Philip.

	Scoring		
Metrics	0 (poor)	5 (good)	10 (excellent)
(1) Number of fish species (# species)	>6	5-6	<5
(2) Percent of individuals that are salmonids (% salmo)	<70	70-96	>96
(3) Percent of individuals that are brook trout (% brook)	<10	10-30	>30
(4) Percent of individuals that are white sucker (% sucker)	>10	1-10	<1
(5) Percent of individuals that are catchable salmonids (% CS)	<8	8-20	>20

Using the criteria retained (Table 4), the total ISCS value was calculated for all sites in the base survey and the DFO survey (Appendix 2). Based on these total ISCS values, narrative criteria for interpreting ISCS scores were also determined ranging through 5 classes from excellent (ISCS scores: 50-45) to very poor (ISCS scores: 5-0) (Table 5). In general, uppermost headwater sites had higher scores, but not always. For example, site 1, although an uppermost headwater site, had a "fair" condition. For several DFO sites that had multi-year samples, the variability between years was relatively small. For example, site 11 was sampled for six years, during which the ISCS scores ranged relatively subtly between 30 (good) and 20 (fair). The largest ISCS variability between years was detected for site 12, which had an ISCS score of 30 (good) in 1999, and 45 (excellent) in 1995.

Discussion

Fish Community Characteristics in Coldwater Streams in River Philip

Our data and analyses documented fish community composition in coldwater streams in River Philip, and its changes with increasing water temperature and decreasing physical habitat quality. High-quality coldwater streams in the research area were almost entirely dominated by three salmonid species including brook trout, brown trout, and Atlantic salmon. Coolwater and warmwater species were typically absent or present in very limited numbers in these streams. These characteristics make coldwater fish assemblages in River Philip simpler than those reported from other regions of North America, which typically harbor "one or a few salmonids, one to three sculpin species, perhaps a stickleback, and a few cyprinids or catastomids" (Lyons et al. 1996, p 250). With a relatively small number of fish species having colonized Nova Scotia since the last glaciation, the province has a reduced number of fish species and lies outside the distributional range of sculpins, a major group of fish present in many other coldwater streams in North America (Gilhen 1974, Scott & Crossman 1973).

With increasing water temperature and decreasing overall habitat quality, coldwater fish communities dominated by salmonids were gradually replaced with cool- to warm-water fish assemblages that are mainly composed of tolerant species. Warmer and/or more degraded sites in our study were inhabited by minnows such as blacknose dace and creek chub, and white sucker. The species richness in these sites was much higher than that of high-quality coldwater streams. These results were consistent with other studies that had reported modifications of coldwater fish assemblages due to environmental degradation (Lyons et al. 1996, Mundahl & Simon 1998).

Between the two habitat variables measured, it was difficult to determine which variable has a stronger effect on fish community changes because the two variables were highly correlated to each other. Possibly, both water temperature and physical

Table 5 Rating categories for ISCS scores and fish community characteristics for each category (adapted from Lyons et al. 1996, Mundahl & Simon 1998).

Total ISCS Score	Rating	Fish Community Characteristics
50-45	Excellent	Comparable to the best coldwater streams in the region; fish communities are dominated almost entirely by salmonids; although exotic brown trout are typically present, brook trout account for a good proportion of total individuals (>30%); Atlantic salmon are usually present; large and catchable salmonids are common; coolwater sea lamprey and 3-spine stickleback may be found in limited numbers; minnows and white sucker are absent.
40-30	Good	Some impairment present; salmonids are still a predominant fish group, but the composition is somewhat different; while brook trout and large salmonid individuals are reduced in abundance, brown trout and Atlantic salmon are found more commonly; sea lamprey and 3-spine stickleback are still limited in abundance; minnows and white sucker are usually absent.
25-20	Fair	Moderate impairment; the proportion of salmonid individuals is reduced; brook trout are rare or absent; large individuals of salmonids are less common; coolwater species (e.g., sea lamprey, 3-spine stickleback, blacknose dace, and white sucker) may be present in good numbers. Total species richness is now slightly higher.
10-15	Poor	Major impairment; salmonids account for only a small portion of fish communities; brook trout are absent; cool water species are present in good numbers; tolerant and/or warmwater species are found commonly; total species richness is relatively high.
0-5	Very poor	Have lost values as coldwater streams; salmonids are absent or found in very limited numbers; various cool- to warmwater species and/or tolerant species such as blacknose dace, creek chub, and white sucker are found, making the species richness higher than that of high-quality coldwater streams.

habitat quality were important factors influencing fish community composition. Alternatively, only one of them was an influential variable, and the other variable was spurious. Further, neither of the two variables may be important, and other variables not measured here, such as stream size, elevation, and water quality, may have more influence on the observed changes in fish communities.

Similarly, there was a lack of data to test the hypothesis that environmental degradation typically raises water temperatures and makes coldwater habitats more hospitable for cool- and warm-water species (Lyons et al. 1996). That water temperatures were generally colder in minimally impacted headwater streams than in more developed downstream reaches can be explained in several ways. Downstream reaches may have been naturally warmer than the headwaters, and, thus, the changes in fish communities may have essentially been caused by natural variability of abiotic conditions (Rahel & Hubert 1991). However, we doubt this is the dominant influence. As an alternative explanation, the natural variability may have been very small and riparian human activities may have raised water temperatures in downstream portions of the watershed (Lyons et al. 1996, Mundahl & Simon 1998). Changes in fish communities could have been caused by a combination of natural and anthropogenic factors.

ISCS Metric Description

The ISCS developed for River Philip is an appropriate tool to assess and monitor the quality of coldwater streams. The ISCS derived from the study watershed was composed of the five most significant metrics that were based on species richness (number of fish species), indicator species (percent of individuals that are salmonids, percent of individuals that are brook trout, percent of individuals that are white sucker), and trophic function (percent of individuals that are catchable salmonids). The integrative nature of this type of biological assessment gives strength to the ISCS that a single-taxon indicator does not possess (Karr et al. 1986, Fausch et al. 1990).

Metric 1. Species richness

High-quality coldwater streams in North America are known to possess limited species richness, and their degradation typically leads to increased numbers of species (Lyons et al. 1996, Mundahl & Simon 1998). The increase in species richness in degraded coldwater streams occurs because the degradation of coldwater streams increases water temperatures, and cool- to warm-water fish species typically inhabiting downstream reaches of the basin system invade the originally coldwater habitats (Lyons et al. 1996). The response of coldwater fish assemblages to environmental degradation is in sharp contrast with that of warmwater fish assemblages, where a decline in species richness usually indicates environmental degradation (Karr et al. 1986, Fausch et al. 1990). In the present ISCS, this metric showed a linear response across the entire gradient of the quality of coldwater streams. This means that the metric had a wide range of "sensitivity", thus the number of species increased constantly with transition from coldwater habitat to warmwater habitat.

Metric 2. Percent of individuals that are salmonids

Salmonids in River Philip include brook trout, brown trout, and Atlantic salmon, and they are representative members of coldwater streams in the study area; the other coldwater species in the area is lake chub, which were not frequently captured in our current study. Brook trout and Atlantic salmon are also the only two species collected in our survey that are assigned with intolerant status, and brown trout have intermediate tolerance. Thus, this metric approximates to "percent of individuals that are coldwater species" and "percent of individuals that are intolerant species". This metric showed a skewed distribution on a graphical analysis, and is a good indicator that distinguished good coldwater streams from poor coldwater streams.

Metric 3. Percent of individuals that are brook trout

Brook trout are known to be sensitive to environmental degradation and to prefer a colder thermal range than brown trout and Atlantic salmon (Eaton et al. 1995, Taniguchi et al. 1997). These previous observations were consistent with our results in that brook trout was associated with the coldest and minimally-impacted headwater streams. This metric was a reliable indicator of excellent coldwater streams.

Metric 4. Percent of individuals that are white sucker

White sucker is a coolwater tolerant species, and is indicative of stream impairment of both warmwater (Karr et al. 1986) and coldwater streams (Mundahl & Simon 1998). In River Philip, white sucker was absent or extremely rare in excellent and good coldwater streams, and became only noticeable in poor coldwater habitats. Thus, this metric successfully distinguished between poor and good coldwater streams in River Philip.

Metric 5. Percent of individuals that are catchable salmonids (age >+2)
This metric was a modification from Miller et al. (1988), who used "percent of individuals that are catchable salmonids (>15cm)". Similar to species richness, this metric showed a wide range of sensitivity, and thus abundance of catchable salmonids decreased constantly as the quality of coldwater streams decreased. However, this metric may be least reliable among the five metrics retained since it showed a high variability at each category of coldwater stream quality (Karr & Chu 1999). In small streams that we surveyed, undisturbed habitats may be more likely to retain habitat complexity (e.g., sinuosity, instream cover, and undercut bank), including pockets of deep pools with which large individual salmonids were typically associated. In contrast, impacted streams possessed more homogeneous stream features, and were often straight and shallow. In some cases, the presence of dams and water diversions for agricultural use has been known to reduce the level of water flow in immediate downstream reaches, diminishing microhabitats where large salmonid individuals are often found.

Ecological Properties of the ISCS and its Potential Use in Stream Management

A multi-metric index to assess stream conditions is based on an assumption that fish communities are diverse, thus their examination provides a variety of ecological information on their ambient conditions (Karr et al. 1986, Fausch et al. 1990). For example, Halliwell et al. (1998) recommended that an IBI should be derived from fish communities containing at least four resident species. However, the ISCS stemmed from a very simple coldwater fish assemblage and, due to its simplified nature, only five metrics were retained. In comparison, the original IBI developed for warmwater streams had 12 metrics (Karr 1981) and a coldwater IBI developed by Mundahl & Simon (1998) was also composed of 12 metrics. As the strength of a multi-parameter index is its large number of metrics, the ISCS is probably a less effective tool in biological monitoring.

This defective aspect could be overcome by adding more metrics. Due to data deficiency, some candidate metrics were not tested in our study (e.g., metrics concerning abundance and condition, and metrics that required the identification of minnows to species), and testing these metrics warrants further attention. In addition, an effective way might be to combine fish assemblages with other taxa. Probably, the best group for consideration in River Philip would be benthic invertebrates. Benthic invertebrates are an important and diverse component of coldwater biological communities (Kerans & Karr 1994, Karr & Chu 1999), and were also easily located by examining stream bottom substrates in our field survey.

We believe that a multi-metric index similar to the ISCS is applicable to other Northumberland Strait streams because they seem to possess a similar species richness and composition (Gilhen 1974). However, the ISCS based on fish assemblages would not be successfully developed in regions that have lower species richness, such as those areas situated at both ends of the province (Gilhen 1974). The use of macroinvertebrates is probably the best approach to inventory and assess biological conditions in these waters.

In further testing and developing an ISCS in other regions, issues on sampling protocols should be borne in mind. First, the sampling season should be specified to allow for comparison between years. The summer low-flow season is usually recommended (USEPA 1997). Second, ISCS variability between years should be further tested. Natural variability of fish composition in headwater streams is relatively large (Danehy et al. 1998), and decisions on stream conditions should not be based on a single year survey result.

While the total ISCS score is a single numerical value, the evaluation of individual metrics can allow us to further examine biological attributes of the data in a general way and to guide us to an appropriate management plan of a given site (Karr et al. 1986). This process can be more effective if coupled with physical and chemical data (Fausch et al. 1990, Snyder et al. 1998). In the present research, for example, site 4 has an overall rating of "good" coldwater quality. A close look at individual metrics indicates that this site did not attain "excellent" status due to very low abundance of brook trout and low abundance of large salmonid individuals; in addition, the vegetative riparian zone width is relatively narrow, and the flow regime is less than ideal because of a small dam built a few kilometers upstream. The water temperature (17°C) is relatively high among coldwater streams in the region. With this information available, a probable conservation management plan for this site would be to restore riparian zones and remove the upstream dam, which would be expected to restore riparian processes and instream physical habitats, and to lower water temperature. As another example, site 8 has a total ISCS score of 45 (excellent status) with a high habitat score (165) and a sufficiently cold water temperature (13°C). This site was exceptional in that brook trout accounted for more than 80% of the fish community. In addition, this site is probably the most unimpaired site among all the survey sites. Habitat protection may therefore be a desirable management option for this site.

The ISCS is also useful in establishing goals for restoration work in a biological sense (Hughes et al. 1990, Karr & Chu 1999). For example, a restoration plan could set an ISCS score of 40 for its biological goal, and the success of restoration work could be assessed numerically relative to this goal. An increase in ISCS scores after any restoration work would indicate its success, while no changes in ISCS scores would mean its failure.

While the ISCS is useful in stream management, solely relying on the index for management decisions may be misleading. The ISCS was developed to evaluate fish communities that are vulnerable to habitat degradation and global warming; however, other ecological traits of fish also contribute to extinction vulnerability. For example, although our study suggests that brook trout are more vulnerable to habitat degradation and global warming than Atlantic salmon in River Philip, the migratory nature of Atlantic salmon indicates larger habitat requirements than brook trout; thus, Atlantic salmon may be potentially more vulnerable than brook trout at the landscape level.

In conclusion, habitat degradation and water temperature increases replaced coldwater fish assemblages dominated by salmonids with warmwater and/or tolerant fish assemblages in River Philip. The ISCS weights fish assemblages in coldest and minimally impacted streams, and assesses sustainability as coldwater streams. There is a concern that increasing riparian development and global warming may reduce the amount of high-quality coldwater streams in many temperate regions, and the ISCS may be a useful tool to inventory and monitor ecological conditions of coldwater streams.

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Appendix 1 List of species that were found in the base survey or DFO survey, and ecological preferences for each species (from Halliwell et al. 1998, Jennings et al. 1998, Smoger & Angermeier 1998).

Family and Common Name	Origin	Tolerance	Feeding	Habitat	Temperature	Spawning
Petromyzontidae						
sea lamprey	N	M	PF	WC	C-W	O
Anguillidae						
American eel	N	T	TC	B	W	O
Salmonidae						
brook trout	N	I	TC	WC	C	SL
Atlantic salmon	N	I	TC	WC	C	SL
brown trout	E	M	TC	WC	C	SL
Cyprinidae						
lake chub	N	M	GF	WC	C	SL
creek chub	N	T	GF	WC	C-W	O
golden shiner	N	T	GF	WC	W	O
common shiner	N	M	GF	WC	C-W	SL
blacknose dace	N	T	GF	WC	C-W	SL
Catostomidae						
white sucker	N	T	GF	B	C-W	O
Ictaluridae						
brown bullhead	N	T	GF	B	W	O
Gasterosteidae						
three-spine stickleback	N	M	IN	WC	C-W	O

Origin	N: native species, E: exotic species
Tolerance	T: tolerant species, I: intolerant species, M: intermediate tolerance
Feeding	PF: parasite feeding, TC: top carnivores, GF: general feeders, IN: insectivores
Habitat	W: water column species, B: benthic species
Temperature	C: coldwater species, W: warmwater species, C-W: coolwater species
Spawning	SL: simple lithophilic spawners, O: others

Appendix 2 ISCS scores for all sites in the base survey and the DFO survey, and their narrative interpretation of stream conditions. Narrative conditions are based on ISCS scores (refer to Table 5).

Site number	Individual score of ISCS metrics					Total ISCS Score	Narrative Condition	Habitat Quality Score	Water Temp.
	# Species	% Salmo	% Brook	% Sucker	% CS				
Base survey									
site 1	5	0	10	10	0	25	Fair	135	17°C
site 2	10	10	5	10	5	40	Good	172	13°C
site 3	10	10	10	10	10	50	Excellent	178	14°C
site 4	10	10	0	10	5	35	Good	115	17°C
site 5	10	10	5	10	5	40	Good	155	16°C
site 6	10	10	0	10	10	40	Good	125	16°C
site 7	10	10	5	10	10	45	Excellent	162	15°C
site 8	10	10	10	10	5	45	Excellent	165	13°C
site 9	10	10	10	10	10	50	Excellent	155	11°C
site 10	0	0	0	0	0	0	Very poor	95	24°C
DFO survey									
site 11 (00)	5	5	0	10	0	20	Fair	149	12.7°C
site 11 (99)	5	5	0	10	0	20	Fair	149	19.7°C
site 11 (98)	5	5	0	10	5	25	Fair	149	14°C
site 11 (97)	10	10	0	10	0	30	Good	149	19°C
site 11 (95)	10	5	0	10	0	25	Fair	149	11°C
site 11 (86)	5	5	0	10	N/A	N/A	N/A	149	16°C
site 12 (99)	5	5	5	10	5	30	Good	155	11.6°C
site 12 (95)	10	10	10	10	5	45	Excellent	155	9°C
site 13 (80)	5	0	0	10	0	15	Poor	126	17°C
site 14 (86)	5	10	0	10	0	25	Fair	115	16.5°C
site 15 (00)	5	0	0	0	5	10	Poor	115	13.7°C
site 15 (99)	5	5	0	5	5	20	Fair	108	15.8°C

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ROAD DENSITY AND POTENTIAL IMPACTS ON WILDLIFE SPECIES SUCH AS AMERICAN MOOSE IN MAINLAND NOVA SCOTIA

KAREN F. BEAZLEY*[1], TAMAINI V. SNAITH [2],
FRANCES MACKINNON [3], and DAVID COLVILLE [4]
[1] School for Resource and Environmental Studies,
Dalhousie University, Halifax, N.S., B3H 3J5
[2] Department of Anthropology,
Harvard University, Peabody Museum,
Cambridge, MA. 02138
[3] Nova Scotia Department of Natural Resources,
Wildlife Division, Kentville, N.S. B4N 4E5
[4] Applied Geomatics Research Group,
Centre of Geographic Sciences, Nova Scotia Community College,
Lawrencetown, N.S. B0S 1M0

Habitat conversion, degradation and fragmentation, and the introduction of exotic species are among the primary factors causing the loss of biodiversity. Road density is a valuable indicator of these anthropogenic factors. Deleterious biological effects extend more than 1000 metres from roads, and road density of 0.6 km/km^2 has been identified as an apparent threshold value above which natural populations of certain large vertebrates decline. Road density assessments in Nova Scotia indicate that many areas exceed this threshold. Multivariate logistic regression analyses indicate relationships between road density, moose pellet distribution, and habitat suitability values. Road density has a statistically significant negative correlation with moose pellets, such that as road density increases, the probability of moose pellet presence decreases. Road density alone and road density in combination with habitat suitability index values predict the presence of moose pellets, whereas habitat suitability values alone do not. Thus, road density may be an indicator of moose habitat selection or effectiveness in mainland Nova Scotia. Biodiversity conservation activities in Nova Scotia and elsewhere could focus on discouraging further road densities above 0.6 km/km^2; protecting remaining roadless and low road density areas; minimizing new road construction, especially in natural areas; decommissioning and regenerating old logging roads; increasing buffer zones between natural areas and roads; and providing road crossings for wildlife in the form of under and overpasses.

La conversion, la dégradation et la fragmentation des habitats ainsi que l'introduction d'espèces exotiques figurent parmi les principaux facteurs responsables de la réduction de la biodiversité. La densité routière est un indicateur précieux de ces facteurs anthropiques. Des effets biologiques négatifs se font sentir à plus de 1 000 mètres des routes, et il semble qu'une densité routière de 0,6 km/km^2 constitue un seuil au-dessus duquel les populations naturelles de certains gros vertébrés diminuent. En Nouvelle-Écosse, la densité routière dépasse ce seuil dans plusieurs régions. Des analyses de régression logistique multivariée révèlent des relations entre la densité routière, la répartition des excréments d'orignaux et les valeurs de qualité de l'habitat. Il existe une corrélation négative significative entre la densité routière et les excréments d'orignaux, l'augmentation de la densité routière réduisant la probabilité de la présence d'excréments. La densité routière seule et la densité routière combinée aux valeurs de l'indice de qualité de l'habitat permettent de prévoir la présence d'excréments d'orignaux, tandis que les valeurs de qualité de l'habitat seules ne peuvent le faire. Par conséquent, la densité routière peut être un indicateur du choix ou de l'utilité de l'habitat pour l'orignal dans la partie continentale de la Nouvelle-Écosse. Dans cette province et ailleurs, les activités de conservation de la biodiversité pourraient mettre l'accent sur le maintien de la densité routière à moins de 0,6 km/km^2, sur la protection des zones sans route et à faible densité routière, sur la réduction de la construction de nouvelles routes, en particulier dans les régions naturelles, sur la mise hors-service et la restauration des vieux chemins d'exploitation forestière, sur l'augmentation des zones tampons entre les régions naturelles et les routes et sur l'aménagement de traversées routières (tunnels et viaducs) pour les animaux sauvages.

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* Author to whom correspondence should be addressed.

Introduction

Currently, 10 - 40% of the world's species are at risk of extinction (Pimm et al. 1995, May et al. 1997, Pimm et al. 2001). In Canada alone, 441 species and populations were listed as extinct, extirpated, endangered, threatened or of special concern in 2003 (COSEWIC 2003). In Nova Scotia, large mammals such as the woodland caribou, wolf, and cougar have already been extirpated, while Canada lynx, American marten, American moose and several other species are considered to be at risk (CESCC 2001).

Conversion, fragmentation and degradation of wildlife habitat by human activities are among the primary factors causing species to decline, along with over-exploitation and the invasion of exotic or introduced species (Soulé 1991). These factors are frequently associated with increases in road density (Noss 1995, Forman et al. 1997, Jalkotzy et al. 1997). Roads have a generally negative overall impact on native biological diversity and ecological integrity (Brocke et al., 1988, Jalkotzy et al. 1997, Gucinski et al. 2001). This includes the deterioration of wildlife habitat, hydrology, geomorphology, and air quality, increased competition and predation (including by humans), and the loss of naturalness or pristine qualities (Forman et al. 1997, Jalkotzy et al. 1997). Roadless areas and areas with low road density are more likely to have greater ecological integrity and/or wildlife habitat value than similar areas with more roads (Noss 1995, Rudis 1995). For species that are sensitive to human activities, such as large mammals and birds, especially herbivores and carnivores, road density is often the most accurate predictor of habitat effectiveness (Lyon 1983, Thiel 1985, Noss & Cooperrider 1994, Noss et al. 1999). Road density has, as a result, been suggested as an appropriate index of human activity and land-use intensity, and as a counter-indicator of suitable habitat for large vertebrates and ecological integrity (Noss 1995, Rudis 1995, Forman 1995, Forman et al. 1997, Noss et al. 1999). This type of surrogate measure is useful where the maintenance or monitoring of biological diversity or ecological integrity are among the objectives, such as regional planning, park, forestry and wildlife management, and protected area system design.

Relatively little research has been conducted to examine the effects of roads on biodiversity and ecological integrity in Canada. This paper focuses on the effects of road density on selected mammals that are found in Nova Scotia by examining results reported in the literature from research conducted elsewhere and with reference to a study on moose and road density in Nova Scotia (Snaith 2001, Snaith et al. 2004). First, examples of road effects and road density thresholds for large and medium-sized mammals are briefly summarized from the literature. Second, results of a GIS-based road density classification and mapping exercise in Nova Scotia are presented. Third, the correlation of road density and habitat suitability with the distribution of moose pellets on mainland Nova Scotia is described to illustrate the possible impact of road density on moose habitat selection, and its utility as a surrogate measure of the effects of human land use on habitat suitability or effectiveness. Finally, general recommendations are made for incorporating road density considerations into biodiversity conservation, and minimizing road effects in Nova Scotia and elsewhere.

Impacts of roads on wildlife

The impact of linear disturbance, (including major highways, primary and secondary roads, trails, railroads, and other development corridors such as pipelines) on wildlife is well documented in the scientific literature. Roads lead to both direct and indirect mortality of wildlife, disturb ranging patterns, and reduce and fragment habitat (Noss 1995, Forman et al. 1997, Jalkotzy et al. 1997). Roads provide access for competitors, predators, and exotic species, increase hunting pressure, and increase mortality by vehicle collision (Houston 1968, Prescott 1968, Peek et al. 1987, Hogg 1990, Forman et al. 1997, Jalkotzy et al. 1997, Rempel et al. 1997, Gucinski et al. 2001). Increased human access to remote areas results in more hunting, trapping, fishing and poaching, disturbance to wildlife, and damage to ecosystems (Brocke et al. 1988, Forman and Hersperger 1996, Gucinski et al. 2001). Roads cause erosion and downstream sedimentation, which lead to changes in vegetation and habitat structure, and the degradation of fish habitat (Gucinski et al. 2001). These negative effects have been shown to extend more than 1000 metres from the road (Forman 1995, Forman et al. 1997). The effects of roads on wildlife can be characterized as of three general types: 1) individual and habitat disruption and habitat avoidance; 2) social disruption and population effects; and, 3) direct and indirect mortality (reclassified from Jalkotzy et al. 1997) (Table 1).

Table 1 Categories of disturbance effects of linear corridors on wildlife

1. Individual and habitat disruption and habitat avoidance

   Wildlife leave or avoid an area or alter their patterns of use, often with a cost in energy expenditure or lost opportunities. In this case, the habitat is effectively unavailable to wildlife.

2. Social disruption and population effects

   Disruption may occur in the structure of a population as a result of the disturbance corridor; for example, differential mortality among classes, or changes in group structure. Behavioral responses to disturbances may have demographic consequences.

3. Direct and indirect mortality

   Direct mortality may arise from wildlife-vehicle collisions, and indirect mortality may arise from, for example, increased access by humans, predators and competitors.

Compiled and adapted from Jalkotzy et al. (1997)

Due to the lack of empirical information on the effects of roads on wildlife in Nova Scotia, a synthesis of the literature from research conducted elsewhere is a useful starting point for assessing potential local impacts. Vertebrate species that are also found in Nova Scotia, such as moose, black bear, white-tailed deer, marten, lynx, bobcat and river otter, have been shown in studies elsewhere to suffer direct mortality as a result of roads. For example, Jalkotzy et al. (1997) report that deer and river otter frequently suffer collision mortality, vehicle and train collisions are the second largest human-caused source of mortality for moose and, in some areas, roadkill mortality may be the single largest cause of death for black bear and may even threaten populations. While the number of road-related mortalities for these species in Nova Scotia is not known, it is reasonable to hypothesize that as road densities increase, the direct and indirect mortality and its potential negative effects on populations of certain species will also increase until the populations decline.

Increasing road access leads to greater indirect mortality through increased hunting, trapping, poaching, predation, competition, and parasitism of species (Brocke et al. 1988, Jalkotzy et al. 1997, Gucinski et al. 2001). Species affected include, among others, moose, black bear, marten, lynx, bobcat, river otter, and birds. For example, field studies have demonstrated that black bear are increasingly vulnerable to hunting as road density increases (Brody and Pelton 1989). Moose population viability has also been shown to be vulnerable to increased hunting pressure near roads, particularly illegal hunting (Lyon 1984, Boer 1990). In Quebec and Ontario, overharvest of moose occurred in areas with greater road access (Timmerman & Gollath 1982, Jalkotzy et al. 1997). A study in New Brunswick found that 92% of moose killed by hunters occurred within 1 km of forest roads (Boer 1990); since the vast majority of moose killed in New Brunswick are killed near roads, "road density affects moose harvest and hence moose population" (Boer 2002). In Newfoundland, unpublished data derived from 35 years of hunter reports have been used by the provincial government's game management agency to correlate hunter access, moose-hunting success, and moose sightings (McLaren 2002). Reports of hunting success were also tracked as access was provided to new areas over a period of about six years, from 1989 to 1995. The records from Newfoundland illustrate that "with increasing road access (and high hunting success enjoyed by Newfoundland hunters), moose density decreases" (ibid).

Roads also cause habitat avoidance, disrupt natural ranging patterns and lead to the fragmentation of populations and habitat, which result in changes in species distributions and population viability (Lyon 1984, Gucinski et al. 2001). Populations are fragmented into smaller subpopulations, which are vulnerable to environmental and demographic fluctuations, inbreeding depression and associated losses of genetic variability, and ultimately local extirpation (e.g., Terborgh & Winter 1980, Shaffer 1981, Gilpin & Soulé 1986). Both bear and moose have been shown to avoid habitat near roads and trails (Forman et al. 1997, Jalkotzy et al. 1997). For example, female black bears in Arkansas utilized habitat within 240 m of roads less than expected, and to black bears in northwestern Montana avoided areas within 274 m of roads and trails in the spring and within 914m of roads during fall (Jalkotzy et al. 1997). In a telemetry study, black bears were found to almost never cross major highways, and crossed roads with low traffic volumes more frequently than those with higher traffic volumes (Brody and Pelton 1989). In Alberta, moose were deflected by snow banks averaging 65 cm along primary roads (Jalkotzy et al. 1997). Road construction, maintenance, and road traffic disturb moose, which often avoid or leave the area (Timmerman & Gollath 1982, Forman et al. 1997, Jalkotzy et al. 1997).

Low-intensity linear developments such as hiking and other recreational trails also disrupt ranging patterns and pose a threat to some species (Knight & Gutzwiller 1995, Miller et al. 1998). Reproductive success and population density of sensitive species such as large herbivores decline as recreational access increases, often as a learned response stemming from hunting pressure (Noss et al. 1999). For example, after cross-country ski development in Elk Island National Park, moose numbers within 500 m of ski trails decreased from pre-development figures (Jalkotzy et al. 1997).

In some cases, it can be argued that roads improve habitat quality by creating new forage areas. Linear development through closed-canopy forest creates edge openings where new growth may create attractive browse areas for herbivores and, in turn, attract predators. Increasing mortality and a likely cascade of other adverse effects, however, may outweigh any benefits of increased forage availability (Jalkotzy et al. 1997, Gucinski et al. 2001). Moose, for example, frequently do not take advantage of the increased forage availability provided by forestry and other roads, including those that are not accompanied by settlement or agriculture (Jalkotzy et al. 1997, Timmerman & Gollath 1982, Forman et al. 1997). Moose in Nova Scotia may also be subject to increased mortality from competition and introduction of the parasite, *Paralephostrongylus tenuis*, associated with white-tailed deer, which invade moose habitat along forest roads, road verges, and other linear canopy openings (Telfer 1968, Prescott 1974, Telfer & Cairns 1986, Pulsifer & Nette 1995, and for an overview refer to Snaith & Beazley (2004)).

Roads are often the avenue and may be the first means by which exotic species invade natural landscapes (Schowalter 1988, Noss & Cooperrider 1994, Forman 1995, Noss et al. 1999, Gucinski et al. 2001). Biological invasions are promoted by disturbance to natural ecosystems such as road construction; and roads and road verges serve as corridors along which exotic species such as invasive plants, pathogenic fungi, and certain animals may disperse (Schowalter 1988, Hobbs & Huenneke 1992, Noss & Cooperrider 1994, Forman 1995). Invading species are generally opportunistic and aggressive and may prey upon or out-compete sensitive and less-aggressive local species (Williamson & Fitter 1996). Natural predators or controls may also be absent for exotic species in the newly invaded area, and exotics may not provide the forage and other necessary resources for other species that local species provide (Usher 1988, Williamson & Fitter 1996).

The effect of roads on most medium-sized carnivores is poorly documented (Jalkotzy et al. 1997). American marten, lynx and fisher all generally avoid human developments and presence, and are more common where human densities are low. In boreal forests in Ontario, marten in logged areas with associated road networks had lower mean ages, were less productive, and suffered higher trapping mortality than those in unlogged forests (ibid.). Lynx avoid crossing major highways and hunting in open areas (ibid.). Declines in lynx populations in Nova Scotia may also be linked to forest trail, road and causeway construction, which facilitates dispersal of competitors such as coyote and bobcat into lynx habitat (O'Neil 2000, Anonymous 2000, Buskirk et al. 2000).

Road density thresholds for wildlife species survival

There are many reports suggesting that, in general, many wildlife species are negatively affected by roads (Lyon 1983, Thiel 1985, Noss & Cooperrider 1994, Forman 1995, Jalkotzy et al. 1997, Noss et al. 1999, Gucinski et al. 2001). As road density increases, so does the likelihood of native species extirpation. The probability of extirpation is correlated to body size, with larger animals becoming extirpated at lower road densities (Forman et al. 1997). Field studies suggest that medium and large-sized vertebrates, including moose, black bear, and white-tailed deer, are adversely affected by increasing road density (Lyon 1983, Thiel 1985, Boer 1990, Jalkotzy et al. 1997, Crete et al. 1981, Timmermann & Gallath 1982, Sage et al. 1983). Forman et al. (1997) have suggested that there is a maximum or threshold road density (0.6 km/km^2) for a "naturally functioning landscape containing sustained populations" of large mammals. Above this threshold, some large mammal populations decline due to disturbance effects and increased mortality. Threshold density values above which wildlife cannot tolerate further road disturbance have been suggested for some species, ranging from 0.25 to 1.9 km/km^2 (Table 2).

Table 2 Summary of road density thresholds for wildlife species and ecosystems

Species (Location)	Road density (mean, guideline, threshold)	Reference
Wolf (Minnesota)	0.36 km/km^2 (mean road density in primary range) 0.54 km/km^2 (mean road density in peripheral range)	Mech et al. 1988
Wolf	>0.6 km/km^2 (absent at this density)	Jalkotzy et al. 1997
Wolf (Wisconsin)	0.45 km/km^2 (limited to areas of pack-area mean road density at or below this level)	Lyon 1984
Wolf, Mountain lion (Minnesota, Wisconsin, Michigan)	0.6 km/km^2 (apparent threshold value for a naturally functioning landscape containing sustained populations)	Thiel 1985, Van Dyke et al. 1986, Jensen et al. 1986, Mech et al. 1988, Mech 1989
Elk (Idaho)	1.9km/km^2 (density standard for habitat effectiveness)	Woodley 2000
Elk (Northern United States)	1.24km/km^2 (habitat effectiveness decline by at least 50%)	Lyon, 1984
Elk, Bear, Wolverine, Lynx, and others	0.63 km/km^2 (reduced habitat security and increased mortality)	Woodley 2000
Black bear (North Carolina)	>1.25 km/km^2 (open roads) >0.5 km/km^2 (logging roads) (interference with use of habitat)	Brody and Pelton 1989
Black bear	0.25 km/km^2 (road density should not exceed)	Jalkotzy et al. 1997
Bobcat (Wisconsin)	1.5 km/km^2 (density of all road types in home range)	Jalkotzy et al. 1997

Category	Road density	Reference
Extremely high	>3 km/km^2	Woodley 2000
High	1 - 3 km/km^2	
Moderate	0.43 - 1.0 km/km^2	
Low	0.06 - 0.43 km/km^2	
Very low	< 0.06 km/km^2	

Note: Some road density figures were converted from mi/mi^2 to km/km^2 for consistency.

Road density in Nova Scotia

In light of the generally negative impacts associated with roads and higher road densities on some native wildlife species and the implications for biodiversity conservation, it is important to understand the distribution and extent of roads and road density in Nova Scotia. GIS-based road density maps were created using road data from the Nova Scotia Geomatics Centre. Road density was represented by six density classes based on km/km^2 (0, 0.01-0.06, 0.06-0.6, 0.6-1, 1-3, >3) and mapped on a 1 x 1 km grid. The classification scheme was adapted from that used in the Interior Columbian Basin Ecosystem Management Study (Woodley 2000), including a zero-road-density class to identify roadless areas. In addition, the 0.6 km/km^2 threshold value identified by Forman et al. (1997) was incorporated into the classification scheme in order to allow subsequent reclassification into areas above and below the threshold.

The road data acquired from the Nova Scotia Geomatics Centre were derived from aerial photography flown between 1987 and 1997. The roads were mapped at a scale of 1:10,000 and were assigned codes to represent the road type; there are approximately 50 recognized road types in Nova Scotia (Anonymous 1990). Other forms of utility corridors and linear developments such as survey and exploration cuts, power lines and pipelines were not included in the road classification or density calculation. The roads were then reclassified into six different categories to produce a roads layer: 1) major highways, 2) primary roads, 3) secondary roads, 4) seasonal roads, 5) active railroads, and 6) abandoned roads/railways, tracks, and trails. Once this was completed, a 1 km^2 grid layer covering the entire province was created. The roads layer was then overlain on the grid layer and calculations were performed to determine the total length of roads within each square kilometer. Having calculated the road density for the grid layer, the density values were then reclassified into the aforementioned density classes (0, 0.01-0.06, 0.06-0.6, 0.6-1, 1-3, >3 km/km^2). This procedure was used to produce two density coverages. One employed all six of the different road, track and trail categories and thereby treated all road types as having equal impact in terms of the density calculation (Fig 1). The other employed only major highways, primary and secondary roads, and active railroads to calculate the density coverage (Fig 2). These two coverages were subsequently reclassified into areas above and below the threshold value of 0.6 km/km^2 (Fig 3 and 4).

The results of this exercise show that several areas of Nova Scotia are above the 0.6 km/km^2 threshold value of road density (Fig 3 and 4). Areas of highest road density exist along the coast, in the Halifax region, in the Annapolis Valley, and along the major highways such as the Trans Canada Highway 101 (Fig 2). The lowest road density classes occur in the interior region of southwestern Nova Scotia. When woods roads, cart tracks and trails are taken into account, the Cumberland-Colchester area has a relatively high road density (Fig 1). These road density patterns may be significant to biodiversity conservation in Nova Scotia. The province is also essentially bisected by Highway 101, fragmenting southwestern populations of wildlife from other populations north east of the highway. In addition, the narrow isthmus connecting Nova Scotia to New Brunswick is further constricted by a highway, other roads, and a railway, effectively isolating some wildlife populations in Nova Scotia from other populations in New Brunswick and the rest of North America.

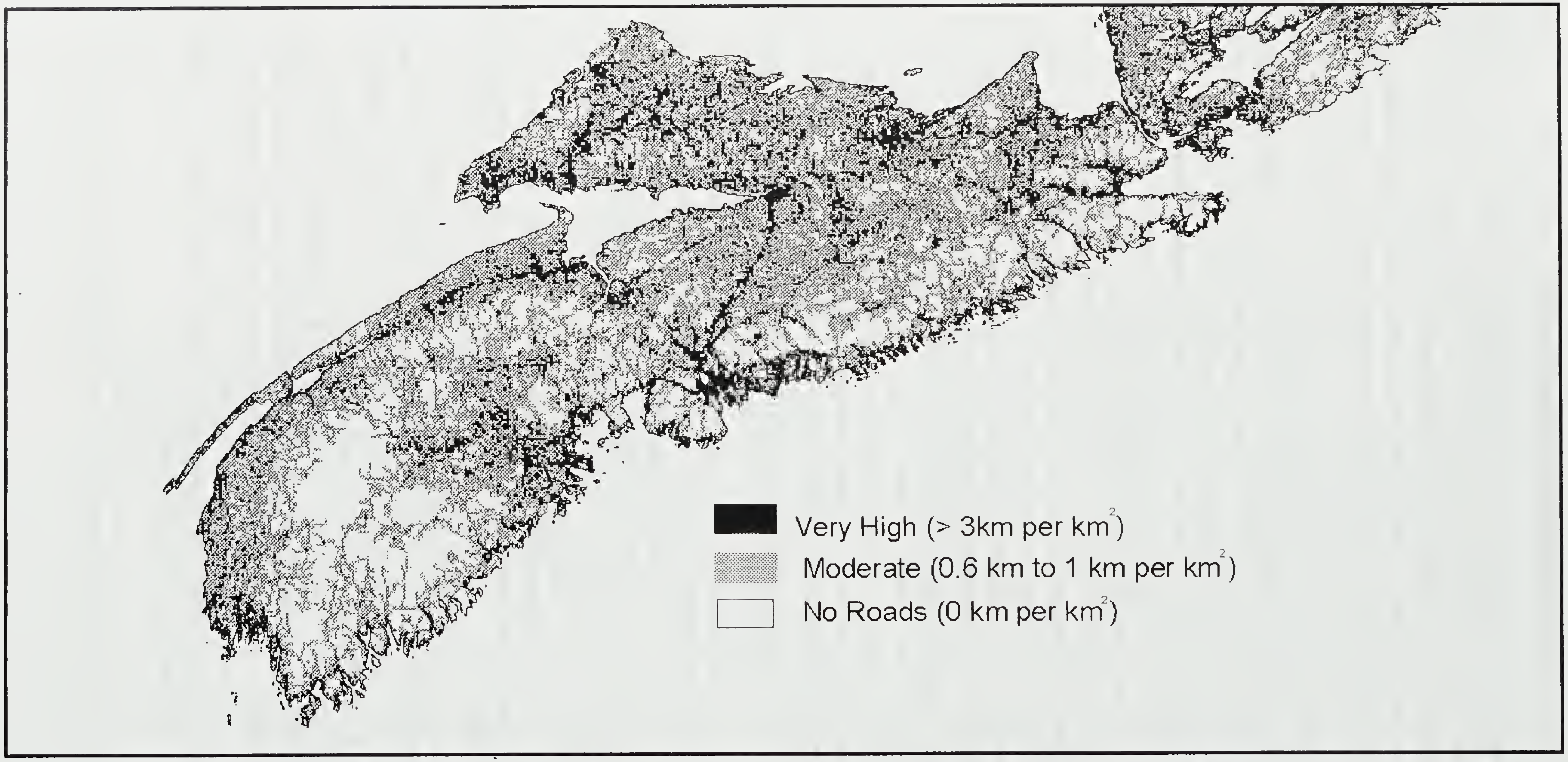
■ Very High (> 3km per km²)
▨ Moderate (0.6 km to 1 km per km²)
□ No Roads (0 km per km²)

Fig 1 Spatial distribution of relative density of roads in mainland Nova Scotia based on all roads, tracks and trails (major highways, primary and secondary roads, seasonal roads, active railroads, abandoned roads and railways, tracks, and trails). Road density was calculated on the basis of the number of linear kilometers of roads, tracks, and trails within each square kilometer. Although six road-density classes were derived (ranging from no roads [zero road density] to greater than 3 km/km^2; refer to text for road density classes), they are reclassified herein for illustrative purposes into areas of very high road density (>3 km/km^2), moderate road density (>0 to <3 km/km^2), and no roads (0 km/km^2).

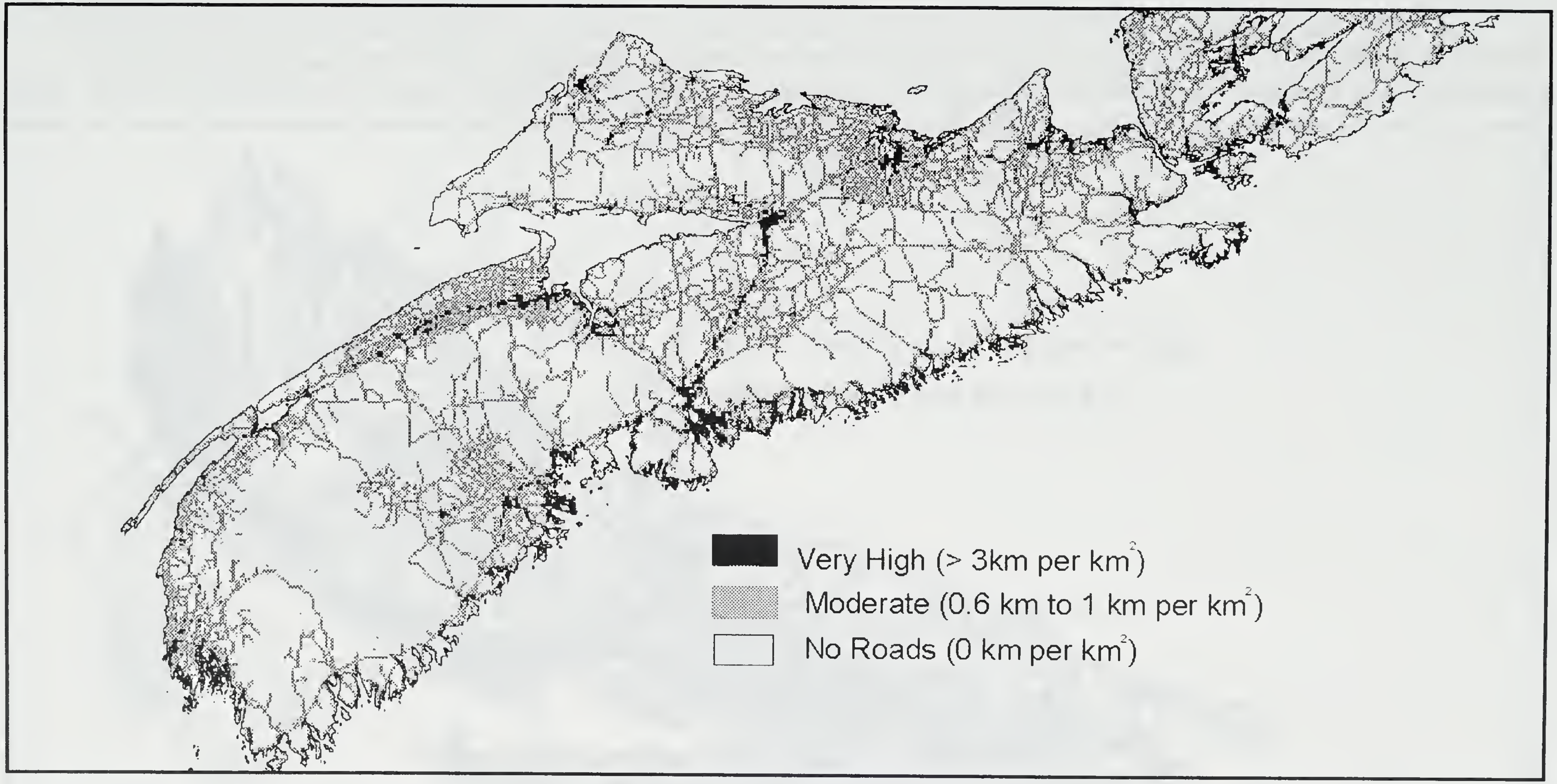

Fig 2 Similar to Fig 1, this illustrates the spatial distribution of areas of very high road density (>3 km/km^2), moderate road density (>0 to <3 km/km^2), and no roads (0 km/km^2) in mainland Nova Scotia. The difference here is that road density was calculated only on the basis of major highways, primary and secondary roads, and active railroads. (Seasonal roads, abandoned roads and railways, tracks, and trails were excluded from the calculation.) As in Fig 1, road density has been reclassified from six density classes to three for illustrative purposes.

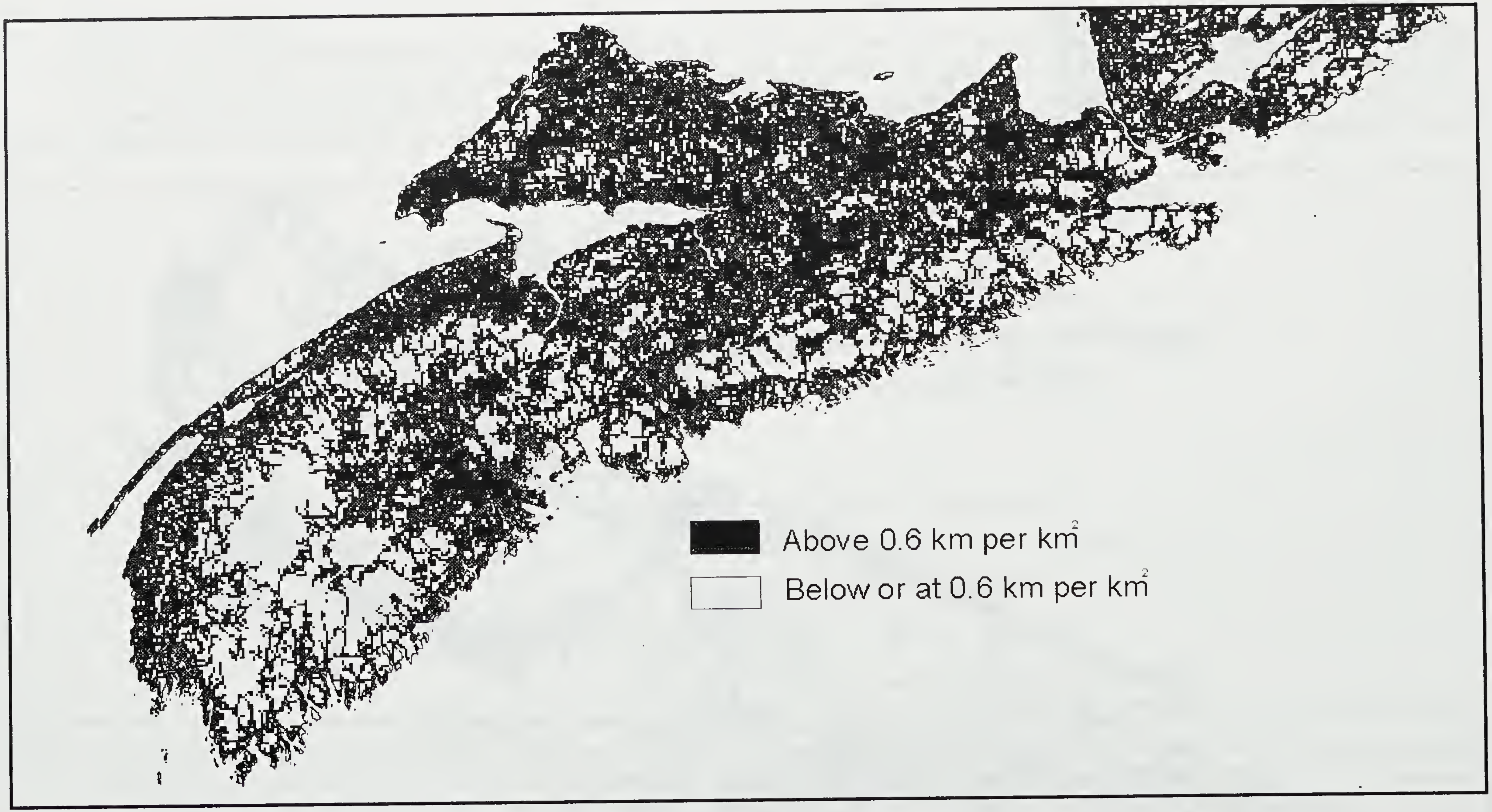

Fig 3 Areas indicated in black are those in which road, track and trail density is higher than the threshold value of 0.6 km/km^2 identified by Forman et al. (1997). As in Fig 1, road density was based on all roads, tracks and trails (major highways, primary and secondary roads, seasonal roads, active railroads, abandoned roads and railways, tracks, and trails).

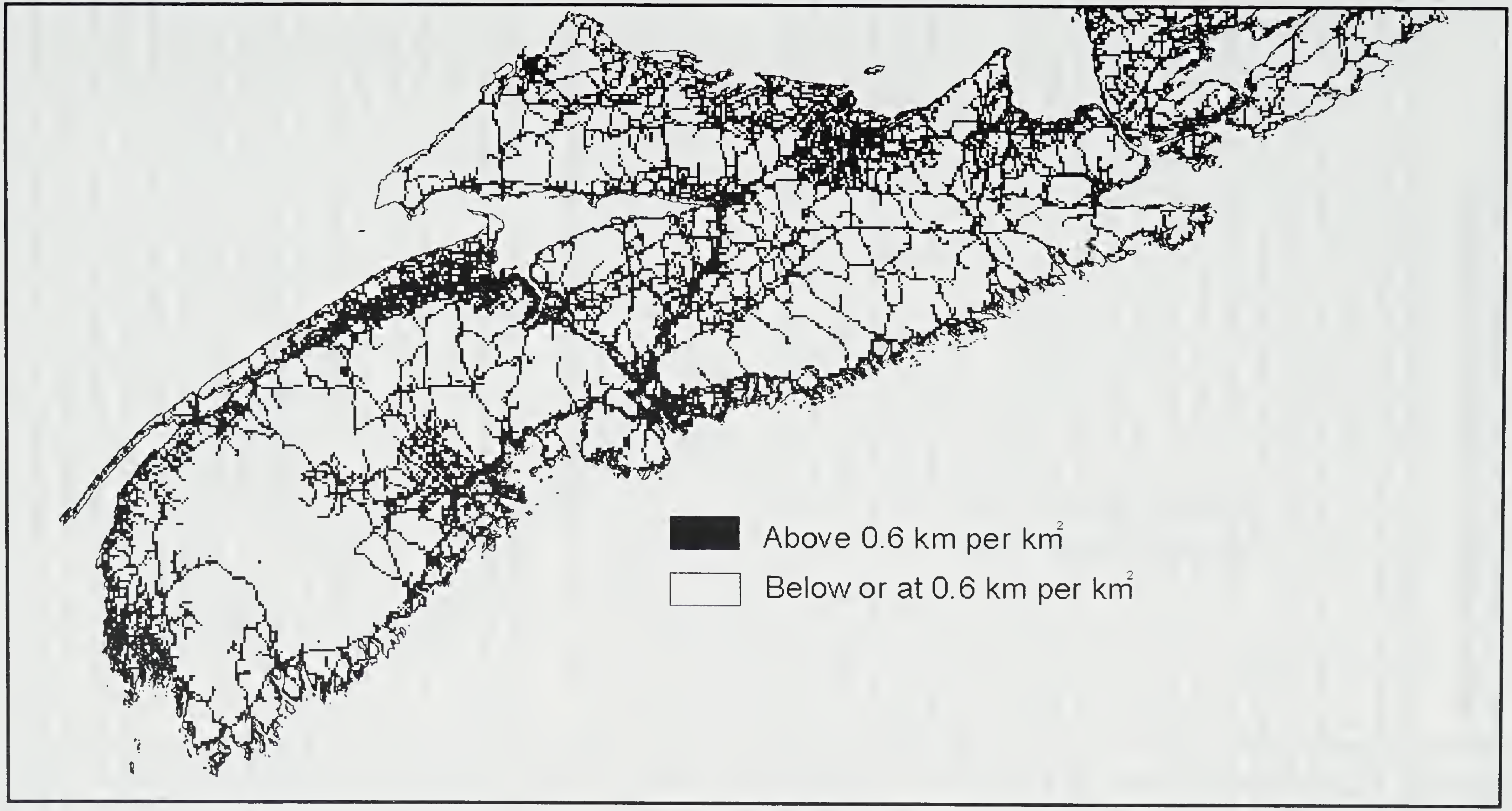

Fig 4 Similar to Fig 3, areas indicated in black are those in which road density is higher than the threshold value of 0.6 km/km^2. The difference here is that the threshold value was calculated using only major highways, primary and secondary roads, and active railroads. (Seasonal roads, abandoned roads and railways, tracks, and trails were excluded from the calculation.)

Effects of road density on moose population viability and habitat selection in mainland Nova Scotia

Road density factors affect population viability and habitat selection by or effectiveness for moose in mainland Nova Scotia (Snaith 2001, Snaith & Beazley 2002, Snaith et al. 2001). For example, the small southwestern/Tobeatic population of moose is isolated from other populations by the section of Highway 101 running from Halifax to Windsor, thus increasing genetic, demographic and environmental risk factors (refer to Snaith & Beazley (2004) for a map of moose distribution in NS). This situation is currently exacerbated by construction activities associated with twinning the Highway from Mount Uniacke to Windsor. High density of woods roads and trails in the Cumberland-Colchester area may result in some greater risk to the current relative stronghold of mainland moose from disease, competition, predation and illegal hunting. Further, the long-term viability of mainland moose populations may be at greater risk due to restricted migration and dispersal to and from New Brunswick and beyond. Road effects and road density may have been factors in the reduction and fragmentation of mainland moose populations, which have resulted in increased risk to both short and long term population viability.

Moose habitat suitability and selection in mainland Nova Scotia appear to be affected by road density (Snaith 2001, Snaith et al. 2001, MacKinnon 2001). Road density was selected as an index of human influence, and moose pellet distribution was selected as an indicator of winter moose distribution/habitat selection in Nova Scotia. The road density coverage (Fig 1) was overlain with habitat suitability index (HSI) and moose pellet distribution maps (Fig 5), and multivariate logistic regression analyses were used to examine the relationship between road density and habitat suitability values in predicting moose pellet presence.

Results indicate that road density is able to predict moose pellet distribution; a significant negative correlation suggests that as road density increased, the probability of moose pellet presence decreased (Snaith 2001, Snaith et al. 2001). All HSI values and individual habitat components, when combined with the effect of roads, could significantly predict pellet presence; however, many of the HSI values and habitat components alone, without taking into account road density, were unable to predict pellet presence.

Road density may be an important factor determining moose distribution and habitat selection. Thus, habitat suitability models conducted in areas with human activities should include considerations of road density. Although in this study road density was more significantly correlated with moose pellet presence/absence than was habitat suitability, there are many other factors that could influence the results. For example, factors such as acidification, pollution, and climate may also affect the presence or absence of moose in areas of greater or lesser road density. It is possible that the effects of higher road densities are stronger in combination with other stressors such as those that occur with species existing at the southern limits of their range, as is the case with moose in mainland Nova Scotia. Although there have been no other studies to specifically explore the correlation between road density and moose populations in Nova Scotia and other Atlantic provinces, the findings reported here (that moose pellet presence is negatively correlated with higher road densities) are consistent with studies in New Brunswick and Newfoundland that correlate hunting success with hunter access by roads and subsequent decreases in moose populations (Boer 1990, McLaren 2002). They are also consistent with findings elsewhere that suggest that for sensitive species such as large herbivores, road density is an accurate predictor of habitat effectiveness (Lyon 1983, Thiel 1985, Noss & Cooperrider 1994, Noss et al. 1999).

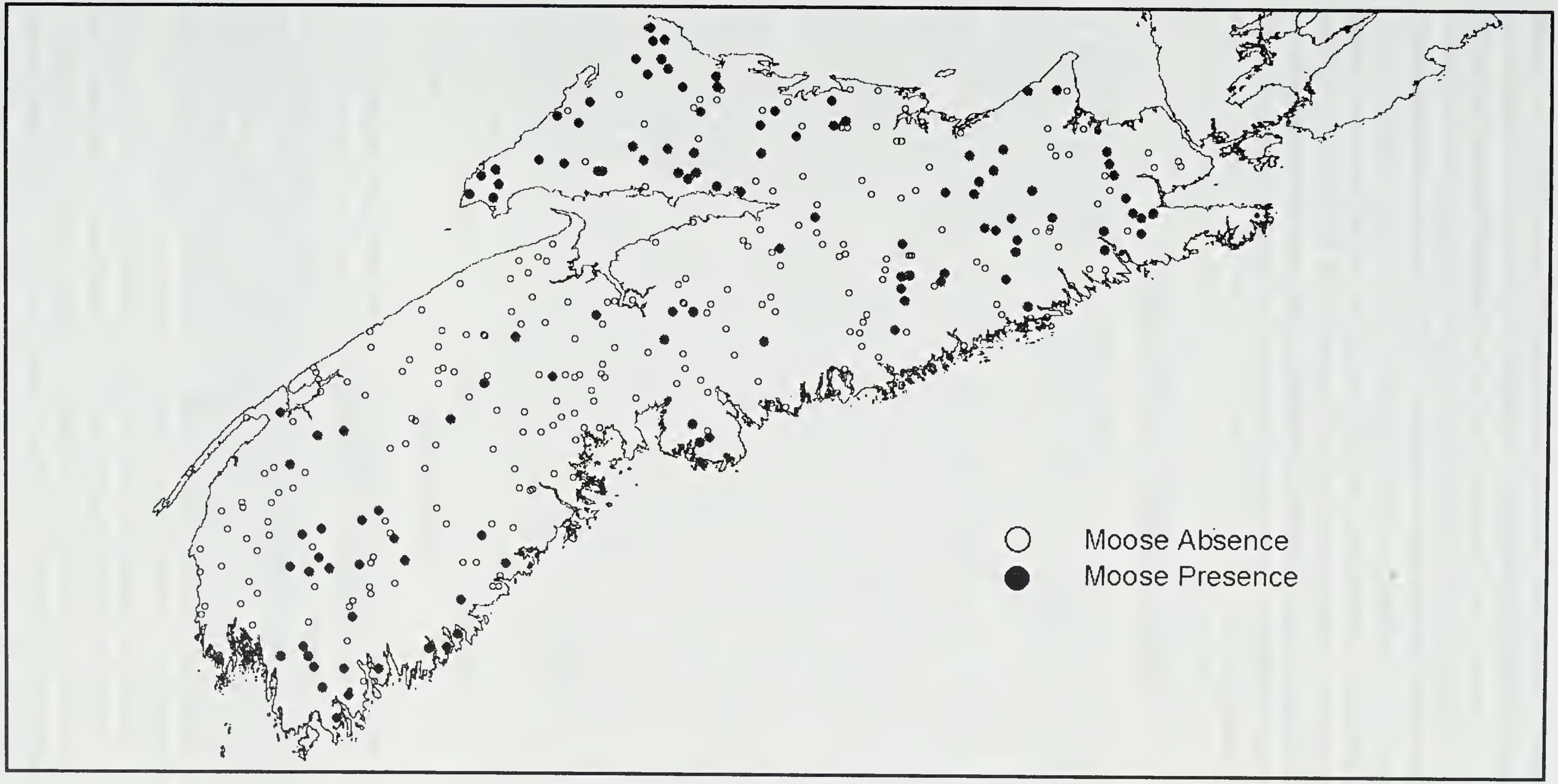

Fig 5 Moose pellet presence/absence in mainland Nova Scotia. Road density and moose pellet presence/absence exhibited a significant correlation when multivariate logistic regression analyses were conducted; as road density increased, the probability of moose pellet presence decreased (Snaith 2001). For this analysis, road density was based upon all roads, tracks and trails (major highways, primary roads, secondary roads, seasonal roads, active railroads, abandoned roads/railways, tracks, and trails). All road-density classes were included (0, 0.01-0.06, 0.06-0.6, 0.6-1, 1-3, >3 km/km^2) (refer to Fig 1).

Further research could examine the relative influences of various factors on moose distribution in mainland Nova Scotia and in neighboring areas. In the meantime, however, given the concerns over the status of moose in mainland Nova Scotia (Snaith 2001, Snaith & Beazley 2002), areas with no roads or low road densities occupied by moose or containing otherwise suitable moose habitat on the mainland should be maintained in a relatively roadless and inaccessible state. New roads could be located to avoid critical habitat components; existing roads could be decommissioned following completion of operations; and, underpasses and overpasses could be constructed to allow movement across major highways. These recommendations are consistent with those of other authors studying the impacts of roads on wildlife species (Peek et al. 1987, Hogg 1990).

Managing roads in wildlife habitat

An increasing body of scientific evidence demonstrates the deleterious effects of roads on wildlife and underscores the importance of maintaining roadless areas. Clearly, road density must be kept below critical thresholds if many wildlife populations are to survive. In addition, existing roadless areas and areas of low road density are important refuges for sensitive wildlife species, such as large-bodied vertebrates and forest-interior species. Thus, any roads constructed in otherwise large, natural areas or through wildlife corridors will have significant negative effects even at lower road densities. The effects of roads extend more than 1 km from the road (Forman et al. 1997), creating a much larger disturbance area than the width of the actual roadbed. For these reasons, it is important to restrict new road and trail access into habitat areas for sensitive species such as moose, lynx and American marten in Nova Scotia.

Roadbeds could be retired and restored after logging and other temporary activities have been completed. In some critical areas, existing roads negatively affecting wildlife while providing minimal benefits to society could be eliminated. Wildlife crossings could be provided at key areas along major highways. For example, in Banff National Park underpasses at the Trans-Canada Highway are used by elk, black bear, wolf, coyote, cougar, lynx and bighorn sheep (Paquet & Callaghan 1996, Gibeau & Heuer 1996, Leeson 1996). Certain species such as grizzly bear, however, are not known to use these underpasses; thus, overpasses may better serve the needs of some species (Horesji 2001).

Conclusion

It is likely that roads exert a negative influence on moose and some other wildlife populations in Nova Scotia, as elsewhere. Increasing road density and intensity of use, as well as new access roads into large, natural areas and wildlife corridors have been demonstrated to cause significant negative effects on some species of wildlife in studies conducted elsewhere. Biodiversity conservation initiatives such as protected areas and recovery plans, forestry, wildlife and parks management, and provincial and regional land-use and transportation planning should take into consideration the direct and indirect effects of roads and road density on sensitive species of wildlife.

Many areas of Nova Scotia exceed the road density threshold (0.6 km/km^2) beyond which natural populations of some large vertebrates have been shown to decline. Road densities appear to affect the selection of habitat by moose. Road density may be among the key factors influencing habitat effectiveness, and thus critical habitat area and population viability, for moose in mainland Nova Scotia, as well as for other species sensitive to the effects of roads such as Canada lynx, American marten, and black bear. Additional research into road effects on wildlife species and ecosystems in Nova Scotia is warranted.

Road density appears to be an appropriate indicator for use in applications where maintenance of native biological diversity forms at least a portion of the management objectives. For example, in regions with various levels of human development and activity, areas with low road density may indicate those with greater potential value for wildlife. This is particularly the case if these areas are also of high habitat suitability in other respects such as forage, thermal and security cover, and denning, nesting or calving areas. However, in Nova Scotia, as in other regions, areas of low road density may also be areas with relatively lower ecological productivity, since these areas may be roadless because of their lower capacity to produce resources, for human enterprises, and thus may also provide low resource productivity for wildlife such as moose. It appears that in Nova Scotia, moose pellet presence is significantly correlated with habitat suitability only when road density is factored in, whereas moose pellet presence is significantly correlated with road density regardless of other habitat suitability factors. As a result, road density may be a better indicator of habitat effectiveness than are habitat suitability indices.

Although areas of low road density may not represent the richest or best areas in terms of net productivity or factors generally used to assess habitat suitability, they are likely to be the areas with the least road-disturbance effects on wildlife and may be preferentially selected by wildlife as a result. Thus, areas of low road density, especially those that also demonstrate other elements of habitat suitability, are potentially important areas for biodiversity conservation; they should be maintained either through wildlife, forestry or other landscape management practices or by designation as protected wilderness areas. New road construction could be minimized, especially in roadless areas or areas of low road densities, and areas important as wildlife habitat and corridors. Roads could be decommissioned and restored after use to minimize access and other adverse effects. Further, wildlife underpasses and overpasses could be constructed on high-use primary and secondary roads and highways so as to minimize collision mortality and indirect negative effects on habitat, wildlife movement, and individuals and populations of wildlife. Road density appears to be a good indicator of human impacts (habitat conversion, degradation and fragmentation; hunting, trapping, fishing, and poaching; roadkill mortality; predation and competition) on sensitive species of wildlife and, consequently, of habitat effectiveness. Thus, measures of road density have utility for identifying areas of conservation value to wildlife.

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Appendix 1: Species list

American marten	*Martes americana*
black bear	*Ursus americanus*
bobcat	*Lynx rufus*
fisher	*Martes pennanti*
lynx	*Lynx canadensis*
moose	*Alces alces americana*
river otter	*Lutra canadensis*
white-tailed deer	*Odocoileus virginianus*
wolf	*Canis lupus*
wolverine	*Gulo gulo*

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A REPORT ON A CONSERVATION PLANNING PROCESS FOR A TERRESTRIAL AND MARINE BIODIVERSITY CONSERVATION VISION IN NOVA SCOTIA

KAREN BEAZLEY[1*], MARTIN WILLISON[1], ROBERT LONG[2] and PAULA MACKAY[3]
[1] School for Resource and Environmental Studies, Dalhousie University,
Halifax, N.S., B3H 3J5, Canada
[2] School of Natural Resources, University of Vermont,
Burlington, VT., 05405, USA
[3] The Wildlands Project,
P.O. Box 455, Richmond, VT., 05477, USA

In May of 1999, a workshop was held to lay the groundwork for a conservation plan to maintain and restore terrestrial and marine biodiversity. The products of the workshop include vision maps and recommendations for biodiversity conservation in Nova Scotia. The wild lands conservation vision identifies existing protected areas, areas suitable for filling gaps in the representation of natural landscape types, and other areas of significant ecological value. Four types of conservation areas are proposed: 1) core areas, to be managed primarily for ecological processes; 2) connectivity zones between core areas; 3) aquatic/marine zones around islands, headlands, bays, lakes and rivers; and, 4) compatible use zones, which provide a buffer function while allowing for human uses. The wild seas conservation vision includes five conservation categories: 1) marine management units; 2) marine protected areas (MPA's) selected with particular attention to the benthic zones (ocean floor); 3) core "no take" zones in areas of unique or sensitive features, species or assemblages; 4) a special management zone for larval retention; and, 5) a "no-dragger" zone to protect fragile deep sea corals.

En mai 1999, on a tenu un atelier visant à préparer le terrain pour un plan de conservation ayant pour but de maintenir et de restaurer la biodiversité terrestre et marine. Les produits de l'atelier comprennent notamment des cartes et des recommandations en ce qui concerne la conservation de la biodiversité en Nouvelle-Écosse. Le projet de conservation des terres sauvages comprend les zones actuellement protégées, les zones qui permettraient de combler les lacunes dans la représentation des types de paysages naturels et d'autres régions importantes sur le plan écologique. On propose d'établir quatre types de zones de conservation : 1) des zones principales, à gérer surtout en fonction des processus écologiques; 2) des zones de connectivité entre les zones principales; 3) des zones aquatiques ou marines autour des îles et des caps, baies, lacs et rivières; 4) des zones d'utilisations compatibles servant de zones tampons et utilisables par les humains. En ce qui concerne la conservation des mers sauvages, on propose cinq catégories de conservation : 1) des unités de gestion marines; 2) des zones de protection marine (ZPM) choisies particulièrement en fonction des zones benthiques (plancher océanique); 3) des zones principales sans prélèvement dans des régions à caractéristiques, espèces ou assemblages d'espèces uniques ou sensibles; 4) une zone de gestion spéciale pour la rétention larvaire; 5) une zone sans dragage pour protéger les coraux fragiles des grands fonds marins.

Introduction

In May of 1999, approximately 50 individuals participated in the Nova Scotia Wild Lands and Wild Seas Mapping Workshop at Dartmouth, N.S. (Beazley et al. 2000). The goal was to lay the groundwork for a long-range, science-informed wilderness conservation plan to maintain and restore terrestrial, freshwater, and marine biodiversity. The grassroots effort was supported by the Northeastern U.S. regional effort of the Wildlands Project, the Ecology Action Centre (EAC), and the Canadian Parks and Wilderness Society (CPAWS). This intensive two-day planning workshop was intended

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[*] Author to whom correspondence should be addressed.
Biodiversity is the natural variability in individuals and species, and the ecological complexes in which they occur. The range of variability occurs at different levels commonly characterized as genes, species, ecosystems, landscapes and biomes.

to permit local naturalists, environmentalists and resource managers to quickly and systematically generate an ecological reserve design map or conservation vision as a preliminary guide for long-term conservation planning. It was structured to synthesize the best available ecological information, using conservation biology and landscape ecology principles, into a system of consensus-based maps of conservation lands and seas capable of sustaining the region's ecosystems over the long term. The objectives of this workshop were to:

- produce preliminary maps that, using the best available knowledge, identify lands and marine areas which merit protection to maintain and restore native species and ecosystems;
- provide recommendations to facilitate implementation of a province-wide reserve network;
- increase awareness of the need for a landscape-scale reserve network in Nova Scotia;
- promote cooperation and support regional efforts to develop reserve systems; and,
- inspire conservationists to strive for bold objectives that assure the long-term viability of species and ecosystems.

The workshop was intended to generate preliminary conceptual and ecological information for regional planning, based on existing and accessible map-based ecological data. Other social and economic factors were not considered, although it is acknowledged that these should be incorporated in future refinements and implementation of a conservation plan. The workshop was carried out with limited resources. Approximately $6000 (CAN) was provided by the Northeastern U.S. regional effort of the Wildlands Project to 1) hire a part-time coordinator through the EAC to assist with organizational details for the workshop, 2) acquire maps, provide lunch, other refreshments and materials for the participants at the workshop, and 3) produce and circulate a summary report. Second, the time allocated during the workshop for generating maps and recommendations was approximately eight hours, since part of the workshop was used to introduce concepts, objectives, and procedures. Third, systematically-collected and mapped ecological data such as species and ecosystem distribution are limited in extent and accessibility in Nova Scotia. Further, no supplementary data or expert opinions other than those provided at the workshop were incorporated. Thus, while the results generated at this workshop represent a valuable vision for conservation planning, further refinement is required.

Methods

The workshop was organized by a Steering Committee consisting of representatives from non-government organizations including the Ecology Action Centre, Canadian Parks and Wilderness Society–Nova Scotia chapter (CPAWS-NS), Science and the Management of Protected Areas Association, and the School for Resource and Environmental Studies, Dalhousie University. Approximately 100 people with knowledge of species, ecosystems or conservation planning were invited to participate as individuals or citizens, rather than as representatives of their organizations. These invitations attracted the target number of approximately 50 workshop participants, which allowed a mix of expertise while ensuring adequate access to mapping tables and opportunities for exchanging ideas and reaching consensus. Participants were provided with a package of preparatory information and asked to bring additional relevant information. The following resource maps were provided by the workshop organizers:

- 1:250,000 base maps (NSDNR 1999 a);
- 1:250,000 candidate wilderness areas (NSDNR 1999 b);
- 1:250,000 provincial crown land (NSDNR 1999 c);
- 1:250,000 provincial parks (NSDNR 1999 d);
- 1:250,000 natural landscapes (NSDNR 1999 e);
- 1:250,000 significant ecosites (NSDNR 1999 f);
- 1:125,000 superior heritage resources (NSDNR 1999 g); and,
- 1:1,000,000 oceanographic chart (DFO 1984).

At the outset of the workshop, participants were invited to produce initial ecological reserve design maps that could be used as a preliminary framework for long-range conservation planning. Representatives from the Steering Committee, the Northeastern U.S. regional effort of the Wildlands Project, the Wildlands Project, and CPAWS described: 1) the process of consensus mapping; 2) definitions of core areas, connectivity zones, and compatible-use areas; and 3) principal components of ecological reserve design, including representation of natural landscape types, species and places of high conservation value (special elements), and habitat for focal species (Soulé 1980, Soulé & Simberloff 1986, Foreman et al. 1991, Noss 1991, Beazley 1997, Miller et al. 1998/99, Noss et al. 1999, Soulé & Terborgh 1999, Beazley et al. 2002a).

For the purposes of mapping, the province was divided into three terrestrial regions (eastern, central and western) and one marine region. Participants worked in groups of approximately ten people per map, circulating among the maps throughout the course of the workshop. The conservation vision maps were created by systematically identifying known and suspected areas of high conservation value. The sites were mapped on transparent (mylar) sheets, which could be overlaid on the resource maps that were provided. Site Nomination Forms were completed for each site, noting the: a) ecological significance of the site; b) level of priority (low, medium or high); c) participants' level of certainty or confidence in the conservation value of the site; d) information sources used; and, e) potential sources of additional information.

Following the mapping exercise, participants collectively defined a series of recommendations to further the biodiversity conservation vision in Nova Scotia. The mapped data and the information from the Site Nomination Forms were subsequently digitized into a Geographic Information System (GIS) by the Northeastern U.S. regional effort of the Wildlands Project, and a summary report (Beazley et al. 2000) was produced and distributed to all participants.

Results

The maps and recommendations produced through the workshop represent the biodiversity conservation vision for terrestrial and marine components of Nova Scotia. The maps depict an integrated network of core areas, areas of connectivity between them, and compatible-use or buffer zones, which the participants consider to be sufficient to maintain and restore the Province's native species and ecosystems (biodiversity) over the long term (> 100 years). The wild lands and wild seas conservation vision maps for Nova Scotia represent the participants' best preliminary selections of areas that should be protected or restored to a relatively natural condition to maintain biodiversity, including healthy ecosystems (Fig 1 and 2). The maps are conceptual and based on existing information, and thus require more-detailed ecological data, field verification and other aspects of refinement. They are, however, a good illustration of key areas of ecological importance and thus high conservation priority, and the extent of wild lands and seas required to sustain species and ecological processes over the long term.

The maps represent the conceptual basis for a long-term (100-year) plan. They are not intended as final conservation plans or reserve designs, but rather as the preliminary, ecological foundation for a more-refined conservation strategy for Nova Scotia. Future planning will require that the concepts represented on these maps be used in conjunction with additional ecological data, as well as social and economic considerations related to, for example, traditional use, agriculture, forestry, fisheries, tourism, recreation, and other aspects of land and sea-based activities, and with input from landowners and other citizens.

Wild Lands: The Terrestrial Vision

Within Canada, Nova Scotia is ecologically diverse for its size; the Nova Scotia Department of Natural Resources, building upon an ecological land classification scheme developed by the Nova Scotia Museum (Davis & Browne 1996), identified 80 natural landscape types across the Province (NSDNR 1994). A stated goal of *A Proposed Protected Areas Systems Plan for Nova Scotia* (NSDNR 1994) is that each of these natural landscape types be represented by a protected Wilderness Area. Thirty-one Wilderness Areas have been designated on Provincial Crown land in Nova Scotia, representing 26 of the natural landscape types. These Wilderness Areas, together with Kejimkujik and Cape Breton Highlands National Parks and other Provincial Parks and Special Places, constitute the backbone of the existing terrestrial protected area system in Nova Scotia, approximately 8% of the total area of the Province; however, 54 natural landscape types in Nova Scotia are not represented (Beazley 1998).

The wild lands conservation vision map (Fig 1) identifies existing protected areas, as well as areas that could serve to represent each of the 54 natural landscape types that are not yet represented, along with other areas of known ecological value in Nova Scotia. Each of the proposed conservation areas is categorized according to its potential role and management component as one of the following:

- Core Area – relatively large area managed to permit ecological processes to function as naturally as possible;
- Connectivity Zone – linkage or corridor area designed to permit large-scale and long-term ecological processes to continue operating within fragmented ecosystems, such as to facilitate movement of animals (migration, breeding, foraging), plant propagules (seeds, pollen, pollinators), and essential abiotic resources such as water and nutrients;
- Near-shore Aquatic/Marine Protection Zone – area protected primarily for its value to aquatic or marine organisms, or for organisms that require an interface between the aquatic and terrestrial realms; or,
- Compatible-use Zone – area managed for low-intensity human uses and designed to buffer or protect core reserves and critical linkages from the ecological impacts of intensive human activities on adjacent lands.

High-priority core areas include existing protected areas and areas of known ecological significance, in which participants have a high level of confidence in their ecological value. Core areas selected for their potential to represent one of the 54 remaining unrepresented natural landscape types are considered to be of high priority

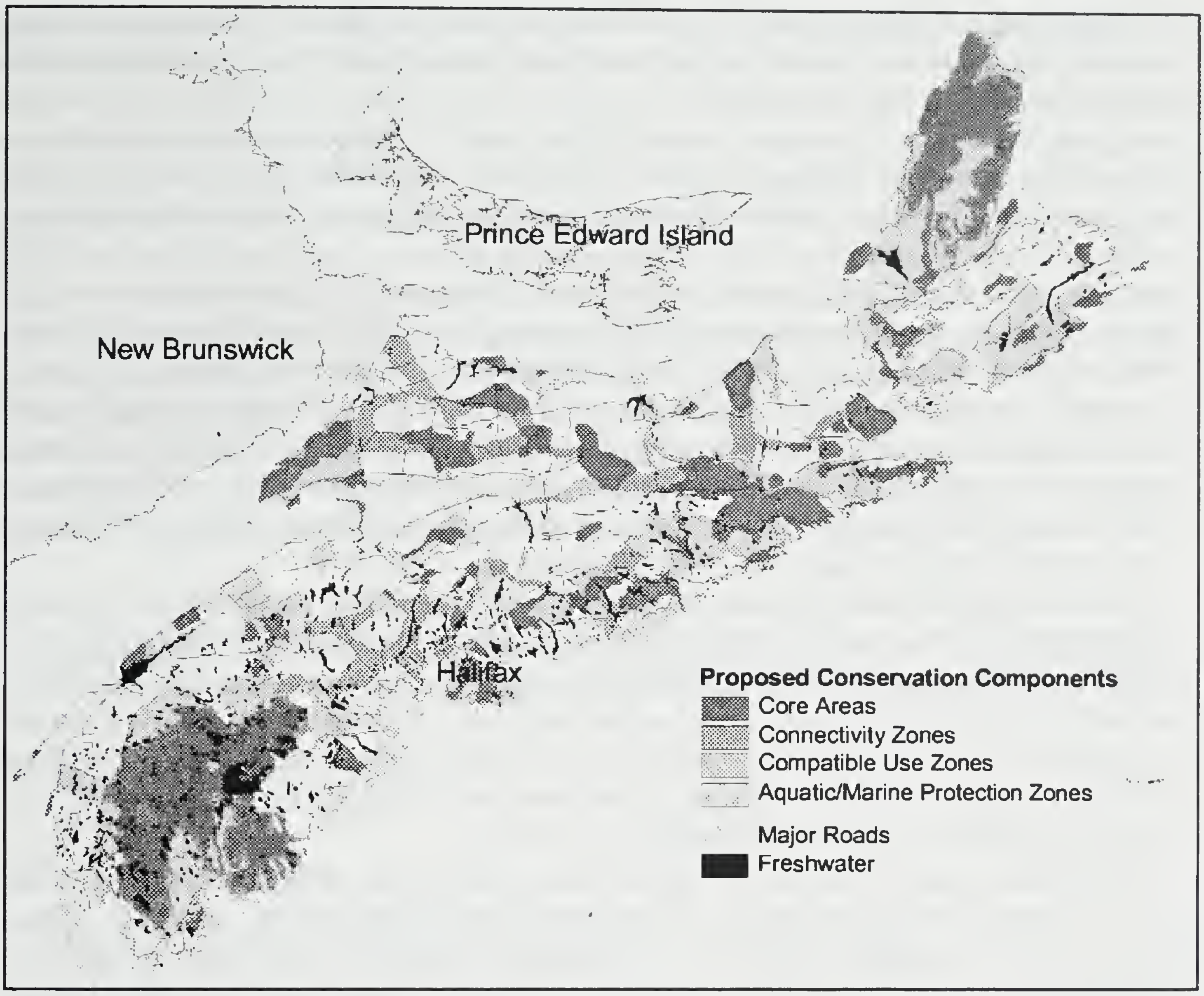

Fig 1 **Wild Lands: A Terrestrial Biodiversity Conservation Vision for Nova Scotia.** The wild lands vision is a result of the Nova Scotia Wild Lands and Wild Seas Mapping Workshop, held in Dartmouth, NS in May, 1999. Important biodiversity conservation components were identified on a series of 1:250,000-scale maps by approximately 50 local experts over a two-day period. Core areas and connectivity, compatible use and aquatic/marine protection zones were defined on the basis of their ecological importance as representative samples of typical natural landscapes, special elements, and habitat for focal species, along with their spatial functions in creating an interconnected system across the landscape. The total area represented within this biodiversity conservation system is 54% of the Nova Scotia land base. It is important to note that not all of this area is intended as protected area; rather, human uses compatible with biodiversity objectives that maintain the specific values for which areas have been selected should be defined and encouraged. (Figure prepared by the Northeastern U.S. regional effort of the Wildlands Project.)

because of their conservation value as representative samples. The participants' confidence in their decisions regarding where precisely to locate these areas within each natural landscape is, however, often categorized as low; further research is required to identify precise locations for representative areas. When potential sites for representation exist on both Crown land and private land, sites on Crown land were selected. This method evolved in an *ad hoc* fashion during the workshop from the participants' assumption that proposing sites for conservation on Crown lands may be a less-controversial approach, particularly in the absence of detailed ecological data.

This approach requires further consideration, since ecologically important or unique elements occur on both public and private lands, and in some cases private conservation initiatives may be more effective.

Important lands and waters for linking together core areas were identified as connectivity zones. Existing protected areas in Nova Scotia and the core areas proposed in the wild lands vision are not large enough on their own to, for example, maintain viable populations of all native species over the long term (Beazley 1997, 1998, Beazley et al. 2002a, Snaith & Beazley 2004a). This is also generally the case with protected areas elsewhere in North America and the world (Newmark 1985, 1995, Noss & Cooperrider 1994). Thus, linkages or areas of connectivity among protected areas are critical for allowing individuals to move between protected areas in order to maintain population size and genetic diversity, to provide source populations for those that suffer local extinctions, and to allow migration and dispersal in response to environmental changes such as climate change (Soulé 1980, Soulé & Simberloff 1986, Noss & Harris 1986, Noss 1987, Dobson et al. 1999).

In the wild lands vision, connectivity zones were tentatively identified in areas of natural land cover between core areas, along riparian corridors and along the coast. Connectivity zones are of intermediate conservation priority because of their important long-term function; however, the precise location of these areas requires further refinement to reflect the specific ecological function, such as the habitat requirements of the populations most dependent upon connectivity for long-term persistence (see for example, Beazley et al. 2002a, Snaith et al. 2004).

Near-shore aquatic and marine protection zones were selected to conserve the terrestrial-marine interface, primarily around islands, headlands, and bays. These coastal zones were identified in areas adjacent to core areas, in areas known to be particularly sensitive or significant in their own right, and/or in areas with relatively little human development. In some cases, these zones also serve as coastal-and-near-shore-aquatic connectivity zones among core areas located near the coast, and as compatible-use zones adjacent to core areas.

Compatible-use zones were drawn around many existing and proposed core protected areas so as to buffer these areas from the negative effects of more-intensive human land-use activity on adjacent lands. Compatible-use zones vary in width depending upon the intensity or likelihood of adjacent human activity that might jeopardize the conservation values for which the core area was selected. The range of compatible human uses would vary from area to area, depending upon the specific conservation value or role of the area in question. The compatible-use zones delineated for the wild lands vision are ranked as having intermediate conservation value because of the buffering function for core areas; they may also serve to provide supplemental habitat for species with relatively large area requirements. The participants were uncertain about the most-effective locations and widths of these areas, thus a low-confidence ranking was frequently applied; further research is required to more precisely delineate the boundaries of the compatible-use zones.

It is important to emphasize that the areas of conservation value that were identified and mapped are limited in at least two ways. First, participants based their selections on their own personal knowledge, expertise or experience, and/or on existing and accessible mapped data provided at the workshop. The selection of areas was not based on a Province-wide, systematic inventory of ecological data collected for this purpose and, thus, both the underlying data and the results contain inherent sampling and perceptual biases. The areas that the participants perceive to have high existing conservation value were identified, whereas areas for which ecological information or knowledge is lacking, or those that are currently ecologically compromised but have strong restoration potential, may not have been identified. Second, some areas were selected primarily for their spatial function in the conservation vision, such as providing connectivity between core areas or as a potential representative sample of a natural landscape type rather than for other known ecological values. With further ecological data, more effective locations for these connectivity zones and representative areas could be selected that combine the conservation roles and other ecological values.

The combination of all four conservation components (core areas, connectivity zones, compatible use zones and aquatic/marine protection zones) represents the terrestrial conservation vision and includes 54% of Nova Scotia's land base (Table 1). This 54% figure is consistent with other studies that suggest that roughly 50% of the land base (Soulé & Terborgh 1999, Soulé & Sanjayan 1998), or between 25% and 75% of a region (Noss & Cooperrider 1994), varying with the particular diversity of species and ecosystems present, is required to prevent further anthropogenic extinctions.

Table 1 Estimated area and percent of Nova Scotia in each conservation component

Category Area	~ Land Area (km^2)	~% of NS Land
Core Areas	14,795	27
Connectivity Zones	3,592	6
Aquatic/Marine Protection Zones[1]	1,136	2
Compatible-use Zones	10,327	19
Total	29,850	54

1. The total area indicated as Aquatic/Marine Protection Zones is 2,496 km^2, which includes areas below the high tide mark. Only those areas above the high tide mark (1,136 km^2) are included in the calculation of land area and percent of NS land area.

It is important to note that the wild lands vision does not depict precise boundaries for protected areas and is not intended to be a blueprint for land acquisition or preservation. Rather, it is intended to serve as a planning guide to identify areas in the province where short-term, intermediate and long-term conservation initiatives could be directed to maintain biodiversity. Conservation initiatives could include compatible human uses and private stewardship options and incentives, such as conservation easements and tax incentives. The terrestrial biodiversity conservation vision may best be achieved through a system of parks, wilderness areas, wildlife management units, and zones for compatible forms of activities such as traditional hunting, trapping and fishing, commercial forestry, farming, small urban and suburban developments, recreation, and ecotourism. The primary management objective within these areas, however, should be to conserve the biodiversity value for which it was selected. For example, commercial-scale, resource-extractive industry is likely incompatible with the conservation function of a core area, however it may be compatible within certain buffer zones. Similarly, traditional forms of hunting may be compatible with the conservation function of a core area. The challenge for future conservation planning is to translate the wild lands conservation vision into detailed, community-based designs and initiatives that integrate compatible land uses into the landscape in ways that also conserve biodiversity and the function of ecosystems.

Wild Seas: The Marine Vision

A significant part of the wild seas mapping workshop involved adapting and applying terrestrially-based concepts of systematic biodiversity conservation planning to the ocean environment. Components such as representation of natural regions, special elements of high conservation value, and critical habitat areas for focal species were integrated into the vision. For example, as with terrestrial conservation planning, the wild seas conservation vision makes use of biogeographic zoning, but in this case employing the marine theme regions (ecozones) as mapped by the Nova Scotia Museum (Davis & Browne 1996). An oceanographic chart at 1:1,000,000-scale (DFO 1984), which shows the bathymetry (depth) of the ocean floor surrounding Nova Scotia, was used as a base map.

The wild seas conservation vision map (Fig 2) includes five major components: 1) marine management units; 2) marine protected areas; 3) core "no take" areas; and, two special management areas, 4) a larval retention zone, and 5) critical deep water coral habitat. The first component, the marine management units, is identified on the vision map as seven primary units, each having distinctive characteristics based on depth and other enduring oceanographic features as defined by the marine theme regions. These marine management units are primarily concerned with pelagic (water column) characteristics and include the following units:

1. Bay of Fundy (inner and outer);
2. Southwestern Banks and Basins;
3. Central Banks and Basins;
4. Eastern Banks and Basins;
5. Eastern Laurentian Shallows;
6. Bras d'Or Inland Sea; and
7. Deep Abyssal Plain.

Each of these 7 units is proposed as a marine management unit in which the precautionary principle will be applied (for a recent review of the application of the precautionary principle in marine environmental management, see VanderZwaag (2002)). The precautionary principle has generally been defined as a mandate to take precautionary measures when an activity raises threats of harm to human health or the environment, even if cause-and-effect relationships are not fully, scientifically established. The essential objective of management within these zones should be primarily to maintain biodiversity and other elements of ecological health, and secondly to maintain fisheries in ways that do not compromise the primary objective. By including the entire marine realm within these management units, no part of the ocean region is open to human uses that do not sustain the health of the ecosystem.

The remaining four major components of the wild seas conservation vision identify areas that possess specific ecological characteristics or perform critical functions in the marine ecosystem. A series of marine protected areas (MPAs) were identified through a process which focused on characteristics of the ocean floor. MPAs provide a higher level of protection for selected regions of the ocean than is generally the case within the rest of the marine management unit. Keeping in mind the history of failures in marine management, particularly in fisheries, the precautionary principle mandates that MPAs be established as insurance against the failure of other conservation and management measures. MPAs were selected both to represent the diversity of marine theme regions, and to protect unique sites containing fragile benthic (bottom) habitats that support both infauna (fauna within the sediments) and epifauna (fauna attached to the seabed or other organisms such as infauna). MPAs are areas from which activities that may damage sensitive natural communities should be excluded. Restrictions may vary somewhat according to each site, and the precise placement and number of these sites should be revised as better information becomes available. Three of the sites

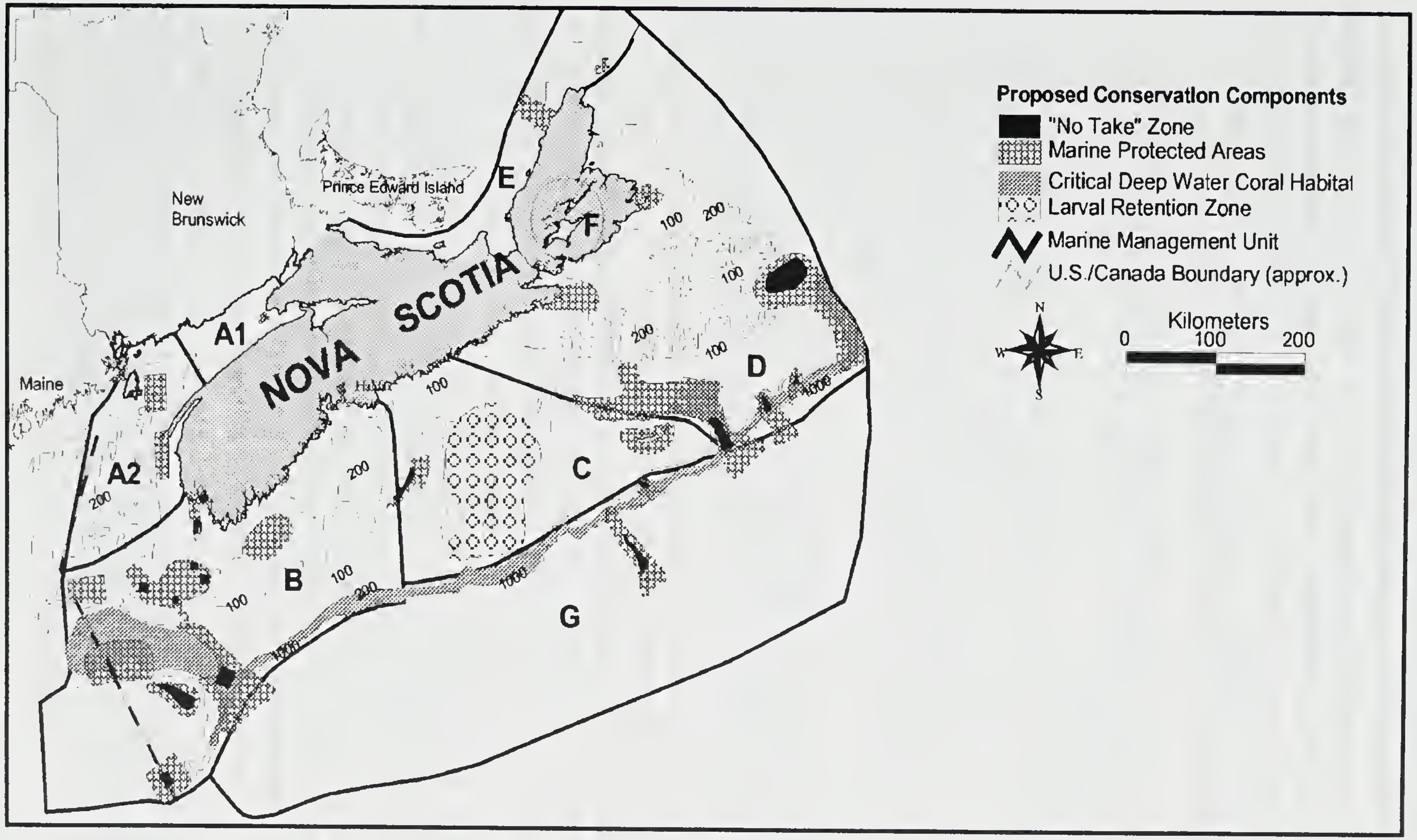

Fig 2 **Wild Seas: A Marine Biodiversity Conservation Vision for Nova Scotia.** The wild seas vision is a result of the Nova Scotia Wild Lands and Wild Seas Mapping Workshop, held in Dartmouth, NS, May 8-9, 1999. Experts were asked to identify and map important marine conservation components on a 1:1,000,000 scale oceanographic chart. Seven marine management units were defined: A 1 and A2) Inner and outer Bay of Fundy; B) Southwestern banks and basins; C) Central banks and basins; D) Eastern banks and basins; E) Eastern Laurentian shallows; F) Bras d'Or inland sea; and G) Deep abyssal plain. Within these management units, potential marine protected areas are identified, along with "no take" zones. In addition to these areas, two large distinctive zones are defined as special management areas due to their sensitivity and importance for larval recruitment and deep water coral habitat. (Figure prepared by the Northeastern U.S. regional effort of the Wildlands Project.)

(Grand Mannan, Roseway Basin, and the Sable Gully) are intended to protect whales as well as benthic fauna, thus some surface-traffic restrictions should apply within their boundaries. Generally, mobile-fishing gear that is dragged across the ocean bottom should be excluded from these MPAs. Participants agreed that more MPAs are needed than the 27 preliminary MPAs that are indicated in the marine vision; however, more knowledge is required before a comprehensive set can be properly identified.

Within some of these MPAs, participants identified 18 areas that have unique or sensitive features, species or assemblages of species. These areas are proposed as core "no-take" zones. Only about 1% of the map is designated as "no-take," which is clearly insufficient. These zones have been included as a matter of principle to indicate that there are areas from which all fishing and other exploitative activity should be excluded. The total no-take area should be larger than shown, but because placement of these zones should be based upon reliable survey information, including that obtained through collection of local fishers' knowledge, only a few tentative proposals have been made in the current map.

In addition to these three standard features of the map (management zones, MPAs, and core no-take zones), two large, distinctive zones were also identified. The first is a larval retention area that results from a gyre (a circulatory ocean current) in the middle of the Scotian Shelf. This area is proposed for special management in view of its role in larval settlement and recruitment of juveniles of several species, including many species important to commercial fisheries. The Department of Fisheries and Oceans regards the gyre as a nursery area and protects part of it for this reason. Management within this special zone should place highest priority on the protection of its capacity for recruitment, which can be viewed as a tool for both biodiversity conservation and fisheries management. This is in contrast to MPAs, which have been designated primarily for the purpose of biodiversity conservation, or management units, which have been proposed primarily for fishery management purposes.

The second special zone lies along much of the Scotian Shelf break, the sharp drop-off at the continental margin, at depths of about 250-2000 metres. Corals, sponges, bryozoans and several other large marine invertebrate animals that are attached to the sediment and bedrock along the continental slope and elsewhere stand up from the bottom to various heights. These may be as high as several metres, although they are usually less than a metre in height. These large bottom-dwelling animals provide habitat for numerous other animals in the same way that plants provide habitat for animals on land. Some of the animals that benefit from the structurally-complex habitat provided by these large sedentary invertebrates are free-swimming, like fish and shrimps, while others are attached to the large sedentary invertebrates. For example, the Gorgonian coral *Primnoa resedaeformis* is often about a metre in height. Individual colonies often have several species of hydrozoans and molluscs attached to them, as well as being surrounded by aggregations of redfish (*Sebastes* spp.). Because the corals, sponges and bryozoans are large, they are readily damaged by mobile fishing gears, such as groundfish trawls and scallop dredges that are dragged over the bottom behind powerful fishing vessels. As a result, these otherwise robust long-lived animals are rendered fragile.

The complex-branching deep sea corals that are found along the edge of the continental shelf off Nova Scotia create the "forest" that is mapped as a special unit. Protection of this coral forest, which also occurs as isolated patches elsewhere on the Scotian Shelf, is of high priority. Damage to this forest by mobile fishing gear is severe, and thus the region has been mapped as a "no-dragger zone". Exclusion of dragged fishing gear, ocean drilling and mining, and any other activity that disturbs the ocean bottom is essential where corals and other structurally-complex features emerge from the bottom. More-precise mapping of these features should therefore be a high priority for future research. Surface traffic and fishing of pelagic species need not be excluded. Once the denser concentrations of corals and areas with dense coral potential have been mapped, more core "no-dragger" areas can be drawn within the coral forest zone.

The wild seas conservation vision map is a starting point for further work, but more input is required before it can be regarded as a "blueprint" for conservation. At the moment, it is simply a blurred picture that needs to be brought into clearer focus if the marine ecosystem is to retain a semblance of health.

Recommendations and other results

In addition to the mapped wild lands and seas visions, the workshop resulted in the formulation of several recommendations to further the visions and the conservation of biodiversity in Nova Scotia. Key recommendations include: 1) collaboration among non-government organizations, local communities, academic researchers and government; 2) review and refinement of the conservation vision maps by the academic community, conservation organizations, local naturalists and other natural resource experts agencies; and, 3) incorporation by federal and provincial governments of the suggestions arising from the workshop into broader planning and management activities (Table 2).

A number of intangible benefits are also expected to result from the mapping workshop, including increased enthusiasm, coordination, communication and research in protected areas initiatives and other conservation projects in Nova Scotia and

Table 2 Key recommendations for biodiversity conservation arising from the workshop

1. Non-government organizations should work together and with local communities, academic researchers and government agencies to further the work of the mapping workshop, in particular and, more generally, the protected areas system and conservation vision for Nova Scotia.

2. The Nova Scotia wild lands and wild seas conservation vision maps should be reviewed and refined by the academic community, conservation organizations, local naturalists and other natural resource experts. Achievable tasks relating to the refinement of the conservation vision should be identified immediately. For example, additional experts and sources of information recorded on the Site Nomination Forms should be consulted, and the information should be incorporated into the maps and associated database. Information on freshwater aquatic ecosystems, in particular, should be sought and incorporated into the conservation vision.

3. Participants should further the visibility and credibility of the conservation vision and the mapping workshop process/results in appropriate ways. For example, papers should be published in regional scientific and other journals.

4. The Province of Nova Scotia, through the Department of Environment and Labour, should undertake a gap analysis and complete the representative system of protected Wilderness Areas for Nova Scotia.

5. The Province of Nova Scotia should develop and implement, in concert with citizens and non-government organizations, a conservation strategy that includes a comprehensive plan for ecologically-sustainable landscape planning. This plan should form the background for land-use planning and Crown land management in the Province.

Table 2 *cont'd*

6. The Province of Nova Scotia and regional and local municipal planning agencies should work cooperatively to incorporate core protected areas, connectivity zones, and compatible-use zones into their land-use planning documents and strategies. Current protected areas are too small, too few and too isolated to sustain ecological health and biodiversity into the future. These existing areas must be supplemented with additional protected areas, functionally connected to each other, and enlarged and buffered from external effects.

7. The Department of Natural Resources should incorporate ecologically sensitive areas, and core, buffer and connectivity zones into their Integrated Resource Management planning strategy for Provincial Crown lands as Categories 2 and 3[1], allowing only compatible and sensitively managed commercial and recreational uses in these areas.

8. The Department of Fisheries and Oceans should incorporate the suggestions generated in the wild seas conservation vision into their ocean management strategy in general, and into Marine Protected Areas planning in particular. All activities conducted in the marine environment should be conducted using the best available knowledge and the most appropriate technology compatible with a precautionary, conservation-oriented approach.

9. In view of the current poorly regulated management of the marine environment, results from the mapping workshop should be made available for use in any appropriate ways that would foster conservation. A precautionary marine management system encompassing the entire marine region and having a hierarchical structure should be established. This hierarchical structure should take careful account of the protection of marine benthic diversity by employing regionally specific fishing gear restrictions.

10. Terrestrial and marine protected areas and ecosystem management should be considered together and integrated in the coastal zone. A biodiversity conservation vision in Nova Scotia requires consideration of the ecological continuum from land to sea. Cooperative and partnership arrangements towards this end should be pursued.

11. The biodiversity conservation vision for Nova Scotia requires integration into a broader regional context; ecological sustainability and biodiversity cannot be successfully maintained in Nova Scotia in isolation from its surroundings. Wild lands and wild seas mapping workshops should be pursued for the remaining Maritime Provinces to provide a link between Nova Scotia and the remainder of the continent. Such an endeavor could also serve to contribute to a regional wild lands and seas vision for the entire northeastern part of the continent.

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[1] **Category 1**: These lands can support a wide range of resource uses *(low level of conflict is anticipated among competing users)*; **Category 2**: Lands with greater competing values and land uses. Most land uses are permitted, but greater planning or modification is necessary to enhance compatibility (*community water supply, wildlife management areas, lands of outstanding scenic, recreational or natural value but not assigned to Category 3*); **Category 3**: Lands specifically allocated to special uses and their availability for other uses is limited or denied (*provincial parks, protected areas, ecological reserves, protected beaches*) (NSDNR 1997, 4).

beyond. It is likely that the workshop resulted in an increased common understanding of the concepts and methods of biodiversity conservation planning, the creation of a common although preliminary vision, and a renewed sense of cooperation, collaboration and passion. Several projects have been initiated to date, although it is difficult to determine whether these are direct results of the mapping workshop. Examples include the "hotspots" project of the Ecology Action Centre's Wilderness Committee, the formation of the Nova Scotia Public Lands Coalition, and further scholarly research into biodiversity conservation planning in Nova Scotia (Beazley et al. 2002 a, b, 2004, Snaith et al. 2004, Snaith and Beazley 2002, 2004 a, b, Smandych 2002). CPAWS-NS and Northeastern U.S. regional effort of the Wildlands Project continue to work towards initiatives that coordinate regional-scaled biodiversity conservation plans, extending beyond provincial and national boundaries in Eastern Canada and the United States.

The methods and format of the workshop proved to be successful. The invitation process resulted in the participation of a near-optimum number and good cross-section of local experts. Timely and consistent completion of the vision was achieved by providing clear goals, objectives, concepts, and mapping instructions to the participants at the beginning of the workshop. Greater circulation of the experts among the three terrestrial-region maps (eastern, central and western) may have provided more-consistent input on a province-wide basis; this could have been accommodated by allocating more time to mapping and less time to introductory presentations, although adequate time to reach a clear understanding of the concepts and methods is also crucial. The creation and circulation of the report, including the vision maps, provided a concrete product for further communication. The GIS-based mapping provided data in a format suitable for future use and refinement as well as for visual communication of the vision. It is critical to the success of the workshop that resources are secured for synthesis, publication and distribution of results.

Existing ecological information for identifying priority areas for biodiversity conservation in Nova Scotia has not been systematically inventoried or mapped, however there are additional data sources that were not included in the mapping exercise. While incorporating additional components may be desirable, it would entail increased preparation and/or mapping time within the workshop itself. Greater synthesis of key ecological data could result in a more-refined and detailed vision, with higher confidence among the participants regarding specific site selection; a follow-up workshop and additional research could serve to facilitate the incorporation of more-detailed and recent data into the vision.

Conclusion

The Nova Scotia Wild Lands and Wild Seas Mapping workshop is an initial step towards the development of a biodiversity conservation vision for the Province. The resulting maps and recommendations illustrate the appropriate scale, both spatially and temporally, for addressing landscape- and seascape-level ecological goals and the complex challenges that accompany them. The wild lands and wild seas conservation visions, and their interface in the coastal zone, will require diligent review and refinement by a broad spectrum of people and organizations. Additional information and collaborative processes are necessary to develop a more refined conservation vision, and economic, social and political considerations must be incorporated. Nevertheless, it represents an important first iteration of a common vision created by a group of experts with wide-ranging experience and knowledge for biodiversity conservation in the Province and its surrounding seas.

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FRESHWATER FISH CONSIDERATIONS FOR AQUATIC CONSERVATION SYSTEMS PLANNING IN NOVA SCOTIA

YOICHIRO KANNO* and KAREN BEAZLEY
School for Resource and Environmental Studies, Dalhousie University,
Halifax, Nova Scotia B3H 3J5
**Present address: Embassy of Japan, Ottawa, Ontario K1N 9E6*

Freshwater ecosystems have suffered severe losses of biodiversity as a result of human activities, however there has been limited attention to freshwater conservation planning. Key criteria for biodiversity conservation in the terrestrial realm (i.e., representation, special elements and focal species) may also be useful in freshwater systems. Thus, we explore freshwater fish conservation in Nova Scotia (NS) with respect to these key criteria. Representation of freshwater fish habitats and communities should include examples of typical and unique biogeographical regions, streams, rivers, lakes, ponds, wetlands, and community assemblages. Special elements include critical habitat for species- and communities-at-risk, and hotspots of diversity and rarity. Sufficient habitat to maintain viable populations of focal species should also be conserved. Focal species 1) are functionally important, such as those at higher trophic levels and key prey, 2) have large-area requirements or are wide ranging, 3) are indicators of habitat quality and/or management practices, and 4) are flagships, such as charismatic and vulnerable species that garner support for aquatic conservation. Considerations of representation, special elements and focal species serve to identify important areas for conserving freshwater fish species, assemblages and habitat in NS. Intolerant and coldwater communities and species such as Atlantic whitefish *Coregonus huntsmani*, Atlantic salmon *Salmo salar*, brook trout *Salvelinus fontinalis*, lake trout *Salvelinus namaycush* and rainbow smelt *Osmerus mordax* warrant conservation attention in NS due to their relatively high ecological importance and/or vulnerability. Other factors for selecting among potential sites for conservation are stability and resilience to broader cross- or transboundary threats such as exotic species, global warming, and acidification. Furthermore, as a consequence of the fluidity and connectivity of aquatic ecosystems, conservation planning should encompass a relatively large portion of selected drainages. Our approach may be useful for other temperate regions in North America.

En raison des activités humaines, les écosystèmes d'eau douce ont subi de graves pertes sur le plan de la biodiversité; cependant, on a prêté qu'une attention limitée à la planification de la conservation des eaux douces. Les critères principaux en matière de conservation de la biodiversité dans le domaine terrestre (à savoir la représentation, les éléments spéciaux et les espèces focales) peuvent aussi être utiles pour les eaux douces. Ainsi, nous examinons la conservation des poissons d'eau douce en Nouvelle-Écosse en fonction de ces critères. La représentation des habitats et des communautés de poissons d'eau douce doit comprendre des exemples de régions biogéographiques, de cours d'eau, de lacs, d'étangs, de milieux humides et d'assemblages de communautés typiques et uniques. Parmi les éléments spéciaux, on compte l'habitat essentiel pour les espèces et les communautés en péril ainsi que les hauts lieux de diversité et de rareté. De plus, il faut conserver suffisamment d'habitat pour maintenir des populations viables des espèces focales. Ces espèces sont importantes sur le plan fonctionnel (qu'on pense aux espèces des niveaux trophiques supérieurs et aux proies principales), ont besoin de beaucoup d'espace ou parcourent un vaste territoire, sont des indicateurs de la qualité de l'habitat ou des résultats des efforts de gestion et jouent un rôle symbolique, comme les espèces charismatiques et vulnérables qui suscitent l'appui en faveur de la conservation des milieux aquatiques. Les facteurs comme la représentation, les éléments particuliers et les espèces focales permettent de repérer les zones importantes pour la conservation des eaux douces, des espèces de poisson, des assemblages et des habitats. En raison de leur importance écologique relativement élevée ou de leur vulnérabilité, il faut accorder de l'attention sur le plan de la conservation aux communautés et aux espèces intolérantes et d'eaux froides, comme le corégone de l'Atlantique (*Coregonus huntsmani*), le saumon atlantique (*Salmo salar*), l'omble de fontaine (*Salvelinus fontinalis*), le touladi (*Salvelinus namaycush*) et l'éperlan (*Osmerus mordax*). D'autres facteurs servent au choix de sites potentiels de conservation, comme la stabilité et la résilience à des menaces transfrontalières, qu'on pense aux espèces exotiques, au réchauffement planétaire et à l'acidification. De plus, la planification devrait couvrir une part relativement grande des bassins hydrographiques choisis. Notre approche peut s'appliquer à d'autres régions tempérées de l'Amérique du Nord.

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* Author to whom correspondence should be addressed.

Introduction

Temperate freshwater fish have suffered severe losses of biodiversity at genetic, population, species, assemblage, and landscape levels due to human activities (Hughes & Noss 1992, Moyle & Leidy 1992). In North America, by 1989, 27 species and 13 subspecies of freshwater fish were extinct (Miller et al. 1989), and 364 species were considered to warrant protection because of their imperilment and rarity (Williams et al. 1989). Although not widely recognized by the public, the proportions of freshwater organisms facing extinction are higher than those of terrestrial species (Karr & Chu 1999, Ricciardi & Rasmussen 1999). Habitat conversion, degradation and fragmentation are the primary causes of fish decline in North America, followed by introduction and invasion of aggressive exotic species, and chemical pollution; additional threats include over-exploitation, acidification and global warming (Miller et al. 1989, Moyle & Leidy 1992). In spite of this apparent loss and degradation, there has been limited attention to aquatic conservation systems planning both in theory and in practice (Maitland 1985, Moyle & Sato 1991).

Biodiversity considerations for conservation systems planning include a combination of three main sets of criteria: representation, special elements and focal species. (Noss et al. 1999). Conservation planning based on a synthesis of these three sets of criteria has only recently been applied to terrestrial systems. We believe, however, that they may also provide a framework for aquatic conservation planning. This paper explores freshwater fish considerations with respect to each of these criteria in Nova Scotia (NS), and discusses considerations required to determine the spatial extent and distribution of a system of aquatic conservation areas.

Representation

Representation is a coarse-filtered approach in which examples of each typical and unique region or ecosystem are selected for conservation. The aim is to protect biodiversity at the ecosystem, community or landscape level, while at the same time capturing many species and genetic variability. In selecting potential sites for conservation within each ecosystem type, preference is usually given to those with the greatest ecological integrity, or with the most natural characteristics or pristine qualities. Representation alone, however, is an insufficient basis for conservation system planning, since some species are not likely to be captured by the representative sample, such as rare species, and other species will require larger habitat area and/or volume and other mitigation measures to maintain population viability over time. Thus, the value of a coarse-filter or representation approach to conservation is not as a stand-alone component, but rather as complementary to fine-filter considerations, such as special elements and focal species.

In freshwater systems, representation could likewise entail the selection of examples of typical and unique aquatic systems, as defined by biogeographic diversity, system types (e.g., lake, stream, pond), and fish assemblages (e.g., cold-, cool-, warm-water assemblages). To achieve representation, the types and distribution of fish communities in NS would need to be defined, and at least one example of each type would need to be conserved or protected. Ideally, more than one example should be protected so as to incorporate redundancy into the system as insurance against the loss of whole communities in the event of natural or anthropogenic disturbances within the protected area. In cases where protection is afforded to more than one population in a connected system, redundancy can also facilitate the recolonization of disturbed reaches from adjacent populations. Our approach focuses on representation at the fish-community level, since information at this level is relatively available. The small number and low endemism of freshwater fish in NS (Gilhen 1974) implies the existence of a relatively small number of fish community types.

Distributions of native freshwater fishes are primarily influenced by abiotic conditions within which biological interactions delimit the ecological niche (Shuter & Post 1990, Rahel & Hubert 1991). As such, fish communities show distinct distributional patterns in conjunction with variation in abiotic environments. A series of studies has found a good correspondence between ecoregions and fish distributions (Rohm et al. 1987, Whittier et al. 1988). Hughes et al. (1990) suggest that aquatic ecoregions can be defined by terrestrial features such as land use, soil, natural vegetation, and land form, based on an assumption that the nature of aquatic environments is determined by their surrounding landscapes. However, other studies indicate that local environmental variables such as water temperature, stream size, stream gradient, and water quality are more important than broader ecoregional characteristics in explaining patterns of fish distributions (Newall & Magnuson 1999, Waite & Carpenter 2000). Longitudinal changes in abiotic factors such as water temperature and stream size are typically accompanied by fish community changes. For example, in many temperate regions of North America, headwater streams dominated by coldwater trout-sculpin assemblages are often replaced by warmwater minnow-sucker assemblages in downstream reaches (Rahel & Hubert 1991). Such linear patterns, however, do not occur strictly as a consequence of local influence on habitat conditions (e.g., coldwater seepage in downstream alluvial plains creates thermal conditions favourable for coldwater species) (Fausch et al. 2002).

In accordance with studies in other regions, the most consistent pattern in fish distributions observed in NS is a distinction between fish assemblages found in coldwater, coolwater and warmwater habitats (Magnuson et al. 1979). Fish assemblages from each thermal guild seem to exhibit habitat segregation at a broad scale. For example, in River Philip watershed, Cumberland County, brook trout is typically associated with cold headwater streams, whereas cool-/warm-water and/or relatively tolerant species such as blacknose dace and white sucker dominate fish assemblages at warmer and/or impacted reaches (Kanno 2002). Peterson & Martin-Robichaud (1989) identified five lake-fish assemblages in NS based primarily on acidity and lake-surface area, but suspected that water temperature was another important factor. Peterson & Gale (1991) also observed that the composition of fish communities in a southern NS catchment changed with acidity and water temperature.

Another important local factor in NS, as elsewhere, may be the type of aquatic habitat, such as stream, lake, or pond. Several species in NS prefer a certain habitat type; for example, northern redbelly dace and pearl dace are associated with relatively slow-flowing waters (Gilhen 1974). In addition, even when a species is commonly found in both lotic (flowing-water such as streams and rivers) and lentic (standing-water such as lakes and ponds) habitats, each group typically exhibits a different life-history strategy and thus may individually warrant conservation efforts (Epifano et al. 2003, Meka et al. 2003). For example, some brook trout populations spend their entire life in streams or in lakes. In addition, other populations use both habitats to complete their life history.

When discussing fish community patterns in NS, the zoogeography of its freshwater fish also warrants attention. Due to the colonization history of freshwater fish after the last glaciation, the highest number of freshwater fish species in NS is found in areas closer to the continental mainland, such as in Cumberland County, and the number of species diminishes towards both ends of the peninsular province, which are further away from the continental colonization source (Gilhen 1974). Thus, this zoogeographic character determines the regional species pool available for fish community composition.

In selecting representative communities, it is also important to differentiate natural fish assemblages from artificial ones, and provide protection for the former. Examples of artificial assemblages are those dominated by exotic species and with species that can tolerate degraded habitats. The introduction of aggressive exotic species can result in artificially increased species richness in the short term, but often results in extirpation of native fish species and decreased diversity over time. Environmental degradation in warmwater streams typically results in reduced species richness (Karr et al. 1986), whereas degraded coldwater streams have higher numbers of species than they naturally would (Lyons et al. 1996, Mundahl & Simon 1998, Kanno 2002). In coldwater streams, which are common in NS, artificial increases in species richness should not be used to argue for habitat protection (Lyons et al. 1996). Future research should determine the types and numbers of fish assemblages that ideally and realistically represent the native freshwater fishes in NS.

Other levels of biological diversity, such as genetic, morphological, population, and landscape diversity, should also be considered, if available (Hughes & Noss 1992). At the genetic level, for instance, the Inner Bay of Fundy populations of Atlantic salmon are considered unique and are designated as an endangered population by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). However, information at levels other than species is not readily available for most freshwater fish in NS. An interim solution to this serious lack of specific data may be to capture diverse geographic representation in the selection of drainages for conservation, based on the assumption that the genetic differences between populations in two distant drainages are larger than those in two adjacent or neighboring drainages (Spidle et al. 2003). Thus, if an opportunity exists to select among several drainages of similar ecological values, geographical separation or distance between drainages may serve as a surrogate for genetic diversity. Another consideration in selecting representative drainages is the current extent and quality of natural land cover in riparian zones and surrounding portions of watersheds. Watersheds with the least anthropogenic disturbances are likely to retain higher levels of ecological integrity and thus may be of higher conservation value, considering, for example, the important functions of riparian zones (Kauffman et al. 1997). Alternatively, remnant examples of drainages that have been widely converted and degraded may also warrant conservation attention as a result of their irreplaceability and the existence of imminent threats.

Finally, the consideration of taxa other than fish, such as frogs or benthic macroinvertebrates, may also be useful in classifying representative aquatic ecosystems, especially in regions with depauperate fish fauna such as NS (Kerans & Karr 1994, Moyle & Marchetti 1998, Karr & Chu 1999). For example, Moyle & Marchetti (1998) combined information on native ranid frogs and fish to develop a watershed-index of biotic integrity in California, which could be used for identifying priority drainages for conservation.

Special Elements

Special elements include critical habitat for species- and communities-at-risk, and hotspots (geographic clusters) of diversity and rarity. Species-at-risk are designated on the basis of small and declining population size and distribution trends, number of occurrences, and threats to population and/or habitat (Elderkin & Boates 1996).

Freshwater fish species that are designated by COSEWIC as at-risk nationally are Atlantic whitefish and the Inner Bay of Fundy population of Atlantic salmon. Provincially, nine species are considered at-risk: four are red-listed and five are yellow-listed, with red-listed species being more threatened (NSDNR 2002) (Table 1). However, the only freshwater fish currently designated as at-risk under Nova Scotia's Endangered Species Act is the Atlantic whitefish. The Millipsigate Lake/Petite Rivière System in Lunenburg County may be the last remaining occurrence of this species globally (Gilhen 2002).

Table 1 NS red-listed and yellow-listed freshwater fish

Red-listed	Yellow-listed
Atlantic whitefish	brook trout
Atlantic salmon	lake trout
Atlantic sturgeon	alewife
Striped bass	fourspine stickleback
	pearl dace

(Source: NSDNR 2002)

Salmonids and other species generally found in coldwater and intolerant assemblages seem disproportionately threatened in NS and may thus represent communities- or assemblages-at-risk; five of the nine red- and yellow-listed species are associated with the coldwater guild (Table 2). The proportion of listed species that are associated with coldwater assemblages is high (56%) in comparison with the proportion of native species in NS that are associated with coldwater assemblages (25%) (Kanno 2002). In comparison to species found in cool- and warm-water assemblages, coldwater species are typically more susceptible to temperature increases, which often result from human activities such as removal of riparian vegetation, water removal, and anthropogenically-induced climate change. In addition, fishes from the coldwater guild in NS also tend to be intolerant species (Table 2), which are sensitive to environmental degradation such as physical habitat alteration and chemical pollution, and are usually the first to disappear when habitat degradation proceeds (Karr et al. 1986, Lyons et al. 1996). Some intolerant coldwater species are also considered vulnerable because of additional factors such as limited distributional range (Atlantic whitefish and lake trout), and late reproductive maturity (Atlantic salmon and lake trout) (Table 3).

While broad-scale habitat segregation occurs among coldwater, coolwater, and warmwater assemblages it is important to note that the actual distributions of each guild may not necessarily reflect preferred macro-habitats. Species that are sensitive to ecological processes such as competition and predation may remain in or retreat to sub-optimal habitats as a survival tactic, especially when inter-specific competition and predation risk are high within optimal habitats. Caution should be exercised to avoid conserving sub-optimal habitats alone as a long-term strategy for conservation of these species.

Hotspots of diversity and rarity comprise another component of special elements. Many fish species are geographically restricted and numerically rare where they occur (Sheldon 1988). In addition, fish species that are endemic, restricted to a small area, or occupy a single drainage basin, (i.e., rare species) are more likely to become at risk, as shown in California by Moyle & Williams (1990). Hotspots of diversity and rarity represent areas where many rare species occur, thus they may present an opportunity to conserve several of these species within a smaller number of sites.

Table 2 Tolerance and thermal guilds of the 33 freshwater fish recorded in NS

Higher vulnerability

	Coldwater species	Coolwater species	Warmwater species
Intolerant species	Atlantic whitefish ** *Coregonus huntsmani* Atlantic salmon** *Salmo salar* brook trout* *Salvelinus fontinalis* lake trout* *Salvelinus namaycush* rainbow smelt *Osmerus mordax*	blacknose shiner *Notropis heterolepis* brook stickleback *Culaea inconstans* Atlantic tomcod *Microgadus tomcod*	Atlantic sturgeon** *Acipenser oxyrinchus* striped bass** *Morone saxatilis*
Intermediate species	northern redbelly dace *Phoxinus eos* lake chub *Couesius plumbeus* pearl dace* *Magariscus margarita*	sea lamprey *Petromyzon marinus* alewife* *Alosa pseudoharengus* common shiner *Luxilus cornutus* fall fish *Semotilus corporalis* threespine stickleback *Gasterosteus aculeatus* fourspine stickleback* *Apeltes quadracus* ninespine stickleback *Pungitius pungitius* white perch *Morone americana* yellow perch *Perca flavescens*	blueback herring *Alosa aestivalis* American shad *Alosa sapidissima* Atlantic silverside *Menidia menidia*
Tolerant species		blacknose dace *Rhinichthys atratulus* creek chub *Semotilus atromaculatus* white sucker *Catostomus commersoni* mummichog *Fundulus heteroclitus*	American eel Anguilla rostrata golden shiner *Carassius auratus* brown bullhead *Ameiurus nebulosus* banded killifish *Fundulus diaphanus*

Source: Kanno 2002

Note: Species with two asterisks (**) are red-listed by the province, while species with one asterisk (*) are yellow-listed (NSDNR 2002

Table 3 Comparison of freshwater fish in NS with intolerance and other vulnerability characteristics

Intolerant species	Species with limited distributional range in NS	Late maturity species
Atlantic whitefish**	Atlantic whitefish**	Atlantic salmon**
Atlantic salmon**	lake trout**	lake trout**
brook trout**	pearl dace**	Atlantic sturgeon
lake trout**	blacknose dace	American eel
Atlantic sturgeon	fall fish	
striped bass	brook stickleback	
rainbow smelt		
northern redbelly dace		
blacknose shiner		
Atlantic tomcod		
brook stickleback		

(Source: Compiled from Beazley 1998, Halliwell et al. 1998).
Note: species with two asterisks (**) are coldwater species, while those with one asterisk (*) are coolwater species.

Focal Species

The focal species concept suggests that a carefully chosen suite or subset of species can serve as surrogates for others, and thus form a multi-species umbrella for conservation planning. A suite of focal species should include those that function in one or more of four different ways, as keystone, umbrella, indicator and/or flagship (Miller et al. 1999). Keystone or functionally important species play a critical role in the community, such as top predators, large herbivores, key prey, and those that transform the system, as do beavers. Umbrella species have large-area and/or volume requirements, or migrate or range widely; as a consequence, protection of sufficient habitat for these species may also serve to protect species with overlapping but smaller habitat requirements. Habitat quality indicator species are those most affected by changes in the quality of the habitat and/or management practices, thus warranting conservation attention. If they are also to be used as indicators for conservation monitoring purposes, they should also meet other pragmatic criteria, such as distribution over a broad geographic area, sampling ease and cost-effectiveness, and differential responses to natural trends and anthropogenic disturbances. Flagship species garner support for conservation initiatives because they are charismatic and/or vulnerable.

Freshwater fish are arguably good candidates for focal species (Moyle & Leidy 1992, Beazley 1998). Fish species often have major effects on the distribution and abundance of other organisms in the waters they inhabit, thus they may serve as keystone or functionally important species. Blueback herring, American shad, alewife, Atlantic salmon, and some species of dace, shiner and stickleback are examples of functionally-important species as predators, prey, or important resources, as identified by experts in NS (Table 4) (Beazley 1998). Species in the Family Cyprinidae (minnows) may constitute important prey species. Losses of these functionally-important species can trigger trophic cascades or other disruptions that affect the entire ecosystem (Terborgh et al. 1999). As a result, it is important to conserve their habitat and other life-history requirements. Functional importance is admittedly a relative factor rather than an absolute, and is also, by definition, associated with the function of certain species or groups of species as opposed to the specific species per se. Thus, there are inherent

Table 4 Criteria for selecting freshwater fish focal species in NS
Response Key: Affirmative (v); Negative (X)

	Keystone/ Functionally Important		Umbrella			Flag-ship	Habitat Specialist Indicator							Vulnerable			
Freshwater Fish in NS	Top Predator, large carnivore/mescoarnivore	Keystone,/prey species, or provides important resources	Space demanding/ wide-ranging in daily or seasonal movements	Migratory species	Requires specialized or defined habitat	Species with broad political support	Limited by dispersal ability	Limited by resource availability	Limited by ecological processes such as flooding	Sensitive to stresses such as acid precipitation, pollution	Sensitive to disturbance by humans, roads, or exploitation	Sensitive to high annual variation in river and stream flow	Dependent upon unimpeded/ unobstructed waterways	Small population in NS	Population declining in NS	Small geographic range/ distribution in NS	Decline in geographic range/ distribution in NS
sea lamprey			√		X		X							X		X	
Atlantic sturgeon			√				X							X		X	
American eel	X		√	√	X		X					X		X		X	
blueback herring		√	√		X		X										
alewife		√	√		√								√	X		X	
American shad		√	√		X		X					√	√	X		X	
Atlantic whitefish			√								√			√	√	√	
lake whitefish					X		√				√			√		√	
Atlantic salmon		√	√	√	√	√	X			√	√	√	√	√	√		√
brook trout			√		√	√	X			√	√	√		X		X	
lake trout					√									√			
rainbow smelt	X		√		√		X						√	X			
northern redbelly dace		√	X		√		√							X			
lake chub		√			X		√										
golden shiner		√			X		√							X		X	

common shiner		√	X				√										
blacknose shiner		√	X		√		√							X		X	
blacknose dace		√	X		√		√									√	
creek chub			X				√							X		X	
fallfish			X				√							√		√	
pearl dace		√	X		√		√									√	
white sucker	X				X		√							X		X	
brown bullhead			X		X		√			X				X		X	
Atlantic tomcod					X		X			√				X		X	
banded killifish		√	X		X		√							X		X	
mummichog		√	X		X		X							X		X	
fourspine stickleback					X		X							X		X	
brook stickleback					√		√							√		√	
threespine stickleback		√			X		X							X		X	
ninespine stickleback		√			X		X							X		X	
white perch					X		X							X		X	
striped bass			√		X		X							X		X	
yellow perch		√			X		√							X		X	

(Sources: Adapted from Beazley, 1998; Beazley et al. 2000)

Note: List of species taken from Gilhen 1974; Beazley, 1998. Column headings adapted from Miller et al., 1999; Soulé and Noss, 1998; Lambeck, 1997; Beazley, 1998; Beazley et al. 2000. Responses indicate areas of consensus among experts surveyed in NS and Maine by Beazley (1998) and Beazley et al. (2000).

difficulties with identifying specific functionally-important species. Nonetheless, it is important to maintain the critical ecological functions of, for example, predator-prey relationships and it is difficult to do so without attention to particular species performing these roles in any given system.

Diadromous (i.e., anadromous and catadromous) fish range widely in space and can function as umbrellas. Atlantic sturgeon, American eel, Atlantic salmon, sea-run brook trout, alewife, American shad, and striped bass are potential umbrella species in NS (Table 4). Anadromous fish spend part of their life cycle in saltwater and migrate to freshwater to spawn, such as Atlantic sturgeon; catadromous fish spend part of their life cycle in freshwater and migrate to saltwater to spawn, such as American eel. Because various life stages of fish have different habitat requirements and these habitats are often widely separated, spatial heterogeneity and movement among spatially separated habitats are critical (Fausch et al. 2002). Due to complex and changing habitat requirements, the conservation of freshwater fish poses special challenges. However, protection of salmon habitat, for example, could be effective as an umbrella function, since it would contain various types of habitats longitudinally, and thus encompass many other aquatic species and ecosystems.

Freshwater fish are proven indicators of aquatic health, as seen in the development of Indices of Biotic Integrity (IBIs) (Karr et al. 1986, Lyons et al. 1996). These studies suggest that various attributes of fish communities such as species richness and composition, abundance of individual indicators, and trophic function, are useful in assessing the quality of aquatic environments. At the species level, presence and abundance of certain taxa are indicative of particular environmental qualities. Atlantic salmon, for example, may be a watershed-scale habitat quality indicator since they are a pollution susceptible/accumulator species and require unobstructed watercourses (Beazley 1998). Similarly, brook trout are dependant upon high-quality coldwater streams that are often associated with stable groundwater discharge (Picard et al. 2003). Atlantic salmon, brook trout, and striped bass are also management indicator species, since all are vulnerable to exploitation and are legally harvested in NS.

Finally, several species are charismatic, important for sport or commercial fishing, and vulnerable, and thus may garner public support for freshwater conservation. In NS, Atlantic salmon and brook trout are popular sport fishes, though opportunities for fishing these species are declining. Declining wild populations of these species (see, for example, DFO 2000) and consequent loss of opportunities for sport fishing may be effectively used to stimulate public support for their conservation.

Salmonids in NS have characteristics that make them vulnerable to habitat degradation and that serve various focal-species functions in conservation system planning. For example, Atlantic salmon is a species-at-risk and a coldwater, intolerant species sensitive to environmental degradation, is considered to be of functional importance, requires large, unobstructed watercourses and a range of habitats for various life-history stages, and provides sport-fishing opportunities, albeit relatively limited at present, in NS (Beazley 1998). Thus, it is an important focal species, with charismatic, keystone, umbrella, habitat quality and management indicator functions. As a result, it is also a potential flagship species, which could garner public support for aquatic conservation planning.

A multi-species approach is critical, however, in freshwater conservation, as in terrestrial systems; no single species or group of species can serve as surrogate for all species and ecosystems. For example, a conservation system plan based solely on the needs of the most area/volume-demanding fish species will fail to encompass species restricted to other locations and habitat types. Broad-scale segregation occurs among coldwater, coolwater, and warmwater habitats as previously noted, and considerations of focal species in all three habitat types are required. It is also important to note that conservation of freshwater systems will require the selection of focal species that depend upon both terrestrial and aquatic habitat, and that include aquatic taxa other than fish (e.g., amphibians). Nonetheless, by accommodating the habitat requirements of a carefully selected suite of freshwater fish, many other aquatic species and ecosystems will also be conserved.

Addressing Broader Threats to Freshwater Fish in Conservation System Planning

Conservation systems that encompass sufficient aquatic and riparian habitat to maintain freshwater fish will go a long way towards protecting other species, assemblages and ecosystems. The conservation of core areas, functional connections between them and buffer areas should serve to address local threats from habitat destruction, chemical pollution, and exploitation. The ability of conservation systems to address broader transboundary threats such as aggressive exotic species, global warming, and acidification, however, is more limited. For example, in cases where populations of exotic species are established, the creation of a conservation area alone will not serve to address the threat. Transboundary stressors such as global warming and acidification may similarly override efforts to protect habitat through conservation area establishment alone. Nonetheless, careful consideration of these threats in aquatic conservation planning can serve to alleviate or mitigate some of the impacts, such as by selecting areas that are more buffered, stable and resilient than others in response to these stressors.

After habitat conversion, degradation and fragmentation, exotic species introduction and invasion are the most important threat to native fish persistence in North America (Moyle & Leidy 1992). Aggressive exotics have become a serious management issue in NS; currently, four introduced species (rainbow trout, brown trout, smallmouth bass, and chain pickerel) are widely and successfully reproducing their populations (Gilhen 2002). The piscivorous nature of chain pickerel and smallmouth bass can modify native fish assemblages (Gilhen 1974), and rainbow trout and brown trout are suspected competitors with native salmonids (Fausch 1988). For instance, predation by chain pickerel may be giving a final blow to the already imperiled Atlantic whitefish in Millipsigate Lake/Petite Rivière system (Gilhen 2002). Furthermore, common hatchery practices, such as stocking of harvest-size brook trout, may be having a potentially negative effect throughout NS, since the mass release of hatchery-propagated species is suspected to reduce genetic fitness of wild populations through interbreeding (Epifanio et al. 2003). Since the removal of exotic species is costly and technically difficult (Kauffman et al. 1997), conservation areas should ideally be established in waters that have not been colonized by exotic species, either by introduction or invasion, and that retain a high level of biotic integrity. We stress, however, that exotic species introductions are essentially an awareness or education issue because humans are the principal source of exotic fish introduction to freshwater systems. This is particularly the case for exotic species that have no salinity tolerance and thus cannot invade on their own through oceanic pathways, such as smallmouth bass. Consequently, aquatic conservation planning should be coupled with appropriate management and public/angler awareness programs, that are ideally supplemented with legislation and regulations that prohibit introductions of exotic species.

Global warming presents significant challenges to the success of aquatic conservation systems. Where species of different thermal preferences or associations coexist, coldwater species are more vulnerable to global warming than cool- and warm-water species due to their requirements for colder waters (Rahel et al. 1996, Eaton & Scheller 1996). If NS warms by 3-4°C during this century as predicted (Hengeveld 2000), coldwater habitats could be reduced significantly throughout NS and, as a consequence, conservation of some current coldwater habitats might not be effective. A more effective strategy could be to identify and protect the coldest streams and lakes in NS, which could hypothetically retain the coldwater thermal range after predicted water temperature increases are accounted for. Aquatic ecosystems with regimes that provide cold water could also be identified and protected, such as riparian vegetation (Blann et al. 2002), areas of groundwater seepage (Biro 1998), rivers with thermally-stratified pools (Nielsen & Lisle 1994), and lake habitats below the thermocline (Olsen et al. 1988). In addition, reaches that cross latitudinal, altitudinal and other temperature and precipitation gradients could be conserved to allow greater opportunity for fish and other species to disperse or migrate to refugia in cooler and/or deeper waters. More northerly and/or higher altitude sites could provide greater protection for species near the upper limits of their temperature tolerances and/or southern limits of their range.

Acidification is another potential impediment to effective conservation of freshwater fish in NS. The southern portion of NS has suffered severely from acidification, since the region is underlain by bedrocks with low buffering capacities (i.e., granite). The region also lies within an area of high deposition rates from industrial emissions upwind in the Great Lakes and eastern seaboard regions (Peterson & Gale 1991, Davis & Browne 1996). Southern NS has experienced significant declines in Atlantic salmon populations (DFO 2000), and several minnows such as creek chub have been affected due to their vulnerability to acidification (Smith et al. 1996). Atlantic salmon have an acidity threshold of pH 5.4 below which it cannot maintain viable populations, whereas many rivers in southern NS have pH of less than 5 (Davis & Browne 1996). Drainages located in areas with relatively higher pH-buffering capacities may represent important refugia for pH-sensitive species and may thus be priorities for conservation to offset the impact of acidification. It is also technically possible to neutralize acidic waters with alkaline substances (e.g., limestone), although it is usually costly (Watt 1986). Reducing stressors at source, however, is a critical goal for addressing acidification problems over the longer term.

While conservation systems may be limited in their ability to address broader, transboundary threats such as aggressive exotics, global warming and acidification, careful planning can serve to minimize the impacts on native freshwater fish diversity. The range limits and tolerances of focal species and assemblages, such as coldwater and intolerant species in NS, provide useful guidelines for conservation systems planning in the context of these threats.

Aquatic Conservation Systems Planning

The maintenance of aquatic species and ecosystems requires the conservation of carefully selected and relatively large areas. We proposed four criteria for conservation system planning, based primarily on considerations of freshwater fish: (1) representation of native fish communities, and genetic, morphological, population and watershed diversity; (2) presence of special elements such as species- and communities-at-risk, and hotspots of diversity and rarity; (3) habitat requirements for viable populations of focal species; and, (4) ability of the area to mitigate or buffer against threats such as exotic species, global warming, and acidification. While the representation approach dictates that a diverse array of native fish community types should be protected (e.g., coldwater assemblages versus warmwater assemblages, lake assemblages versus river assemblages), coldwater and intolerant guilds are especially important in NS due to their vulnerability, thus represent a special element of high conservation value. Coldwater and intolerant species such as salmonids also share several characteristics that suggest they warrant special consideration as focal species, such as functional importance, large-area/volume requirements, habitat- and management-related sensitivities, and charismatic features. For example, Atlantic salmon serves functional, umbrella, habitat quality and management indicator roles, and is a potentially important flagship species.

It is difficult to delineate the spatial extent and distribution of an aquatic conservation system plan to protect freshwater fish in NS. As a general guideline, on the grounds of inter-connectivity of aquatic systems and other considerations, we advocate that relatively large portions of selected drainages be managed for conservation objectives. Aquatic systems are interconnected in several dimensions, particularly in running waters, which are connected longitudinally. Obstructions such as dams affect downstream habitats by modifying flow regime, water quality, and water temperature (Karr & Chu 1999), as well as upstream reaches by blocking movement of aquatic organisms (Winston et al. 1991). In addition to migratory species, recent evidence suggests that resident fishes often display extensive movement (Peterson & Bayley 1993, Fausch et al. 2002). Thus, aquatic protection requires relatively large, longitudinally connected areas.

Freshwater systems are also connected horizontally with adjacent lands, and this may be especially true in headwater streams due to their strong linkage to riparian processes (Gomi et al. 2002). The quality and width of riparian zones are often associated with the health of aquatic communities (Barton et al. 1985, Snyder et al. 1998). At a larger scale, the proportions of forested land and other natural ecosystems within drainages are often a predictor of healthy fish communities (Steedman 1988, Frenzel & Swanson 1996). Therefore, protection of aquatic habitats also necessitates protection of terrestrial areas well beyond typically narrowly-defined riparian buffer zones.

Movements of purely freshwater fish are generally restricted to the watershed in which they occur, since in most circumstances they are not able to traverse oceans and terrestrial ridges. This implies that connectivity in aquatic protected areas is typically discussed in the context of "within a watershed", but not "between watersheds". This suggests that watersheds are an appropriate management unit of aquatic systems.

Finally, there is a general paucity of data and knowledge required for freshwater protected areas planning. Sufficiently-detailed information, such as to define appropriate widths for riparian zones, or to identify seasonal migration patterns and other habitat requirements of species of interest, often does not exist and/or is hard to obtain. As a result of the complexity and uncertainty involved, we argue for extensive conservation of selected drainages or watersheds, as a precautionary and less data-intensive approach than more selective protection of smaller sites in every watershed, though ideally both approaches are required. NS is comprised of 44 geographically small primary watersheds, which can be further divided into several drainage systems (Davis & Browne 1996). The typically small size of drainage areas in NS provides a pragmatic advantage for aquatic conservation, since smaller areas are required to conserve a good portion of an entire drainage system. Thus, the critical aspect is to select the most appropriate drainage systems in NS for extensive protection, based on systematic and ecologically-sound criteria.

In conclusion, there is a critical need to systematically plan and establish freshwater conservation systems in NS. Key criteria for terrestrial protected areas planning such as representation, special elements, and focal species, are applicable to conservation of freshwater fish. While an array of native fish communities should be considered, intolerant coldwater fish such as Atlantic salmon and brook trout are disproportionately important and warrant priority attention, due to vulnerability, ecological importance, and umbrella and other surrogate conservation planning functions. The selection of freshwater conservation areas should also take into account the relative abilities of different drainages to buffer or minimize the effects of exotic species, global warming, and acidification. Our approach may be useful for other temperate regions in North America.

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RESERVE PLANNING ON PRIVATE LAND HOLDINGS OF THE FORESTRY COMPANY, STORA PORT HAWKESBURY LIMITED: CAPE BRETON ISLAND AND EASTERN MAINLAND NOVA SCOTIA

CHRISTOPHER A. MILLER
Wetlands Research Centre and Department of Biology,
University of Waterloo
Waterloo, Ontario, Canada
N2L 3G1

The forestry company, Stora Port Hawkesbury Limited, owns 280 properties throughout Cape Breton Island and eastern mainland Nova Scotia with a total cumulative area of 24 590 ha. This study utilized a coarse filter analysis to determine which of these land holdings support representative and outstanding natural features compatible with the creation of a system of privately-owned nature reserves. Aerial photographs were used to document each property. Approximately 35% of the private land holdings were caught by the coarse filter to be considered candidate protected sites. Significant features identified include old-growth forests, wetlands, ravines, headwaters, lakeshores, coastlines, lagoons, talus slopes, forested floodplains, ephemeral rivers, oxbow lakes, riparian zones, and mountain barrens. Other studies have subdivided Nova Scotia into a series of 80 distinct natural landscape units, most of which have few or no protected areas. A Stora-owned system of nature reserves could help fill significant representation gaps within the province-wide system of protected areas, since nearly three-quarters of landscape units containing Stora properties are inadequately represented with existing protected sites. Other Stora-owned properties are located along significant waterways or positioned adjacent to larger existing protected areas. Later stages of this project will field-verify interpretations of the coarse filter analysis and further refine the list of candidate protected sites presented here.

En Nouvelle-Écosse, la société forestière Stora Port Hawkesbury Limited possède 280 propriétés dans l'île du Cap-Breton et dans l'est de la partie continentale; la superficie totale des propriétés est de 24 590 ha. La présente étude utilise le principe du filtre brut pour établir quelles propriétés renferment des caractéristiques naturelles représentatives et exceptionnelles pour la création d'un réseau de réserves naturelles privées. On a utilisé des photographies aériennes pour documenter chaque propriété. Environ 35% des propriétés privées analysées ont été retenues pour analyse plus poussée. Parmi les éléments importants repérés, on compte des vieilles forêts, des milieux humides, des ravins, des eaux d'amont, des rivages de lacs, des côtes, des lagunes, des pentes d'éboulis, des plaines inondables boisées, des rivières éphémères, des méandres morts, des zones riveraines et des landes de montagnes. Dans d'autres études, on a subdivisé la Nouvelle-Écosse en 80 unités de paysage naturel, dont la plupart renferment peu de zones protégées ou aucune. Comme près des trois quarts des unités de paysage qui comprennent des propriétés de la Stora ne sont pas bien représentées dans les sites protégés actuels, un réseau de réserves naturelles appartenant à la société Stora pourrait contribuer à combler des lacunes importantes dans la représentation des types de milieux dans le réseau provincial de zones protégées. D'autres propriétés de cette société sont situées le long d'importantes voies navigables ou sont adjacentes à de grandes zones protégées. Dans les étapes ultérieures du présent projet, on validera sur le terrain les résultats de l'analyse par filtre brut et améliorera la liste des sites candidats présentés dans le présent document.

Introduction

It is difficult to establish a truly representative system of protected areas in Nova Scotia using public lands alone, since less than 30% of the provincial landmass is owned by the Crown (see: Sutherland 1996, 1997). Even if all public lands were to be designated as protected, for instance, regions lacking sizable tracts of Crown land, such as the Annapolis Valley, the Bras d'Or Lake Plain, the Northumberland Strait area, or the Bridgewater drumlin field district, would still be without substantive areas of protected wilderness. Thus, in Nova Scotia, it is imperative to incorporate systems of privately-owned nature reserves into the existing system of publicly-owned protected sites, to properly address a conservation strategy for the province.

Two non-governmental organizations have been responsible for securing most protected private lands in Nova Scotia: (1) The Nova Scotia Nature Trust (NSNT 2002), and (2) the Nature Conservancy of Canada (NCC 2002). Since its establishment in 1994, the Nova Scotia Nature Trust has secured conservation easements and stewardship agreements at several sites throughout the province, and has acquired eight private properties for nature reserves (NSNT 2002). Particular attention has been focused on Hants County (Anonymous 1997, Sutherland 1998), the Cape Breton Highlands (Anonymous 2000), and the coastal plain flora areas of southwestern Nova Scotia (Sam 2000). The Nature Conservancy of Canada has acquired twenty properties in Nova Scotia since 1970, with a total cumulative area of 3000 ha (NCC 2002). Recent additions to their system include properties at Musquodoboit Harbour, Gaff Point, and Prospect High Head (NCC 2002). Most private reserves in Nova Scotia, however, have been established opportunistically, with few having been systematically selected to complement other conservation initiatives within the province. As a result, large gaps still exist within the provincial system of publicly-owned protected wilderness sites, threatening the long-term survival of many important ecosystems in large portions of the province.

Here, I examine the private land holdings of the largest forestry company operating in Nova Scotia, Stora Port Hawkesbury Limited, to determine which of its private properties maintain representative and outstanding natural phenomena of greatest importance for protection within a system of privately-owned nature reserves. This study marks the first serious attempt in the province to systematically incorporate properties from a single landowner into a privately-owned network of nature reserves. A standardized coarse filter analysis was used to assess the ecological importance of each private land holding. This technique focuses biological conservation at a macro scale level, and usually involves the protection of communities, ecosystems, habitats, and landscapes (Noss 1987, Hunter et al. 1988, Gauthier 1992, Scott et al. 1993, Noss & Cooperrider 1994). For examples from Nova Scotia, refer to Leduc & Smith (1992), Lynds & Leduc (1995), and Beazley (1997). Research presented here represents the initial phase of a multi-stage hierarchical analysis that will culminate in the eventual protection of Stora's most ecologically significant private land holdings (Miller 1998).

Objectives

(1) To identify representative and outstanding natural features on the private land holdings of Stora Port Hawkesbury Limited.
(2) To create a list of candidate sites from which properties can eventually be selected as nature reserves.

Study Area

Stora Port Hawkesbury Limited is a subsidiary of Stora-Enso Limited, based in Sweden. It maintains cutting rights on approximately one third (620 923 ha) of Nova Scotia's Crown-owned property, including most public lands from Cape Breton Island and eastern mainland Nova Scotia. In addition to these public land holdings, the company also owns a number of private properties outright, scattered throughout this same general region (Fig. 1).

At the onset of this project, Stora Port Hawkesbury Limited maintained two hundred eighty privately owned properties on Cape Breton Island and eastern mainland Nova

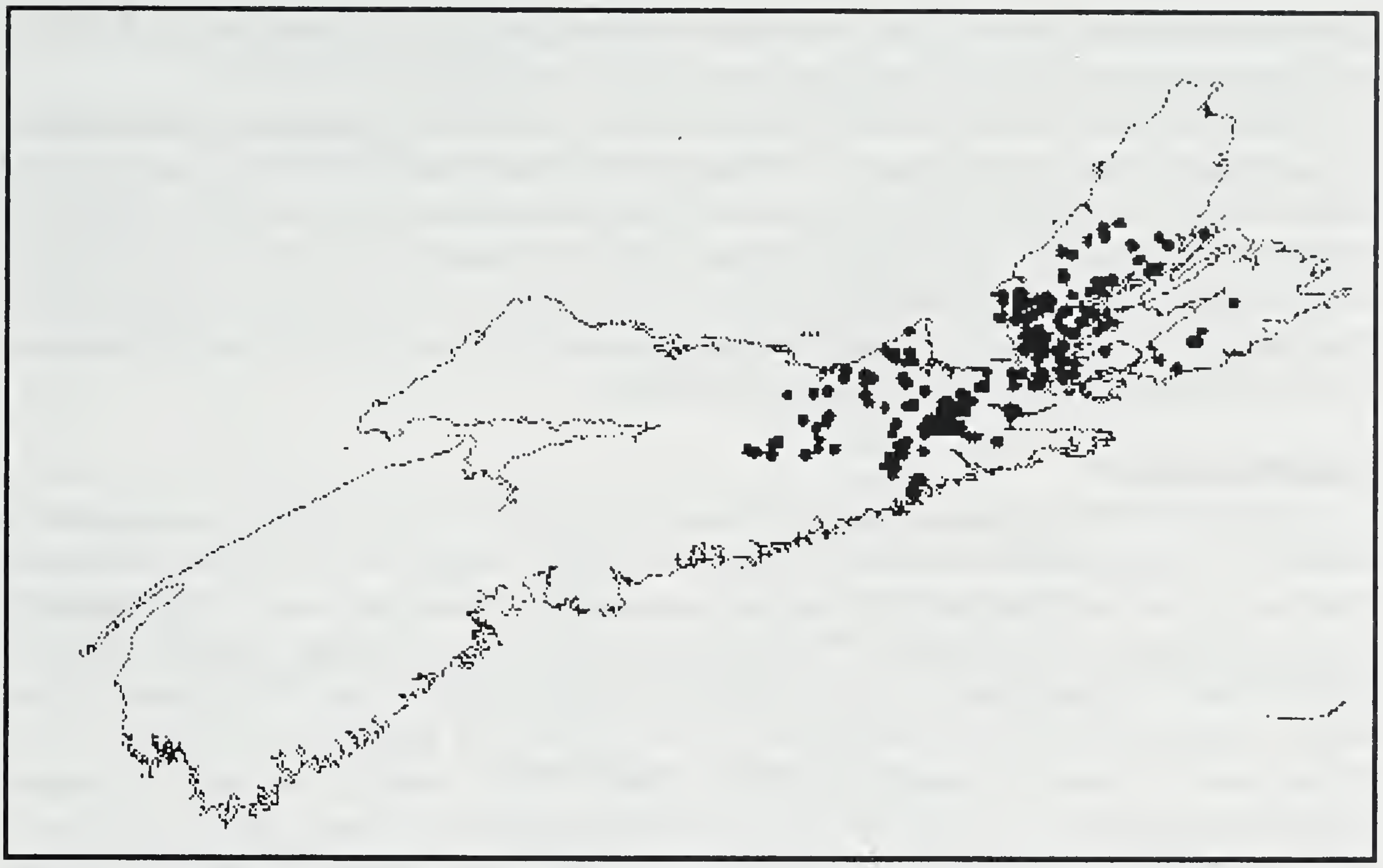

Fig 1 Private land holdings of Stora Port Hawkesbury Limited

Scotia, ranging in size from 0.4 ha to 819.9 ha, with a total cumulative area of 24590 ha. Since several of these private land holdings were positioned adjacent one another, the total number of distinct areas maintained by Stora at the time of this project was somewhat less than two hundred eighty, totaling one hundred eighty-six distinct land units. Ninety-five parcels were located on Cape Breton Island, forty-three in Antigonish County, twenty-four in Guysborough County, and twenty-four in Pictou County. Three additional properties in Cumberland and Colchester Counties, and one on Prince Edward Island, were not included in the present study.

Methods

The private land holdings of Stora Port Hawkesbury Limited were subdivided into three groups, including those from (1) Cape Breton Island, (2) Guysborough County, and (3) Pictou/Antigonish Counties. Properties from Cape Breton Island were labeled C1 through C95, those from Guysborough County from G1 to G24, and Pictou/Antigonish Counties from P1 to P67. A labeled parcel of land consisted of either an individual Stora property or a conglomerate of adjacent properties. For detailed maps showing the locations of each private land holding refer to Miller (1998).

All private land holdings were analyzed solely from aerial photographs. This approach is comparable to other coarse filter analyses that have been carried out in Nova Scotia (e.g. DNR 1994a, Leduc & Smith 1992, Lynds & Leduc 1995). Stora properties in Guysborough, Pictou, and Antigonish Counties were assessed using 1997 aerial photographs, while those from Cape Breton Island were assessed using 1993 aerial photographs. These were the most recent aerial photographs available for these areas at the time of this analysis. Aerial photographs were unavailable for eighteen of the one hundred eighty-six Stora land holdings, leaving these properties unassessed at the conclusion of the coarse filter analysis. A supplemental review still needs to be carried out, therefore, to determine which of these properties possess natural features of importance to a Stora-owned system of nature reserves.

The coarse filter analysis used for this project involved two standard approaches to the selection of protected areas. The first assessed the representation potential of the Stora-owned properties, while the second examined outstanding natural phenomena. Additional significance was attached to properties located along important waterways or positioned adjacent to existing protected wilderness sites. Any land holding found to possess important features, either for representivity or outstanding natural phenomena, was considered a candidate protected site.

Representation

A representative approach to the design of a system of protected areas seeks to establish reserves in all landscape divisions of a given region so that a full spectrum of biodiversity and ecosystem-types can be protected (e.g. Margules et al. 1988, Bedward et al. 1992, Noss & Cooperider 1994, Beazley 1997, Primack 1998). Two primary land classification systems were in place for Nova Scotia at the time of this study: (1) an eighty landscape scheme developed by the Parks and Recreation Division of the Department of Natural Resources (DNR 1994a, 1997), and (2) an eight ecoregion partition developed by Environment Canada (Environment Canada 1995). The private land holdings of Stora Port Hawkesbury Limited were assessed using the eighty landscape scheme, as it was the most detailed biogeographical description of the province available at the time. It also better enabled the Stora-owned properties to be placed in a provincial representation context, as the publicly-owned system of protected wilderness areas in Nova Scotia was developed using the eighty landscape scheme and representation levels had already been predetermined for each of its landscape units (DNR 1994a, Lynds & Leduc 1995).

Land holdings identified from the aerial photographs as maintaining ecosystems characteristic of an underrepresented landscape were flagged as potential candidate protected sites. Representivity was determined by comparing landforms and forest-types identified from the aerial photographs with those expected from published summary descriptions of each natural landscape-type (DNR 1997). Properties with intact ecosystems, but occurring in landscapes already satisfactorily represented with protected areas, were typically rejected as candidate nature reserves unless they also maintained features of outstanding natural value or other attributes important for inclusion within a system of protected areas.

Outstanding features

In addition to representivity, the private land holdings of Stora Port Hawkesbury Limited were also assessed for the presence of outstanding natural features. Table 1 lists the outstanding landscape elements that were actively searched for on the aerial photographs. All are identifiable at the 1:10 000 scale of the aerial photographs. This list was compiled, in part, from suggestions by staff members of the Protected Areas Division of the Nova Scotia Department of Environment and Labour. Additional outstanding natural features not included on this list were also considered if they were observed on the aerial photographs. These results were later supplemented with published information on geologic formations, significant wetlands, old forests, and rare species (e.g. DME 1979, Lynds 1992, Stora 1994).

Table 1 List of outstanding natural features actively searched for on the aerial photographs of Stora-owned properties.

Outstanding natural features	
Mountain coves	Lake islands
Mountain barrens	Ephemeral ponds
Talus slopes	Old forests
Salt marshes	Cliffs
Tidal flats	Coastal islands
Bogs	Coastal barrens
Fens	Coastal ledges
Freshwater marshes	Beaches
Swamps	Dunefields
Estuaries	Uncommon forest-types
Lagoons	Inland barrens
Eel grass beds	Riparian zones

Results and discussion

Sixty-eight of the one hundred eighty-six Stora land holdings were found to contain representative or outstanding natural features of some significance to conservation and were subsequently caught by the coarse filter (Fig. 2). Twenty of these properties exhibited no evidence of recent forest harvesting. The other forty-eight had been modestly logged in some areas, but maintained important and intact ecological features elsewhere. The one hundred three land holdings that did not pass through the coarse filter analysis were largely clearcut, extensively roaded, or had been partially converted to conifer plantations.

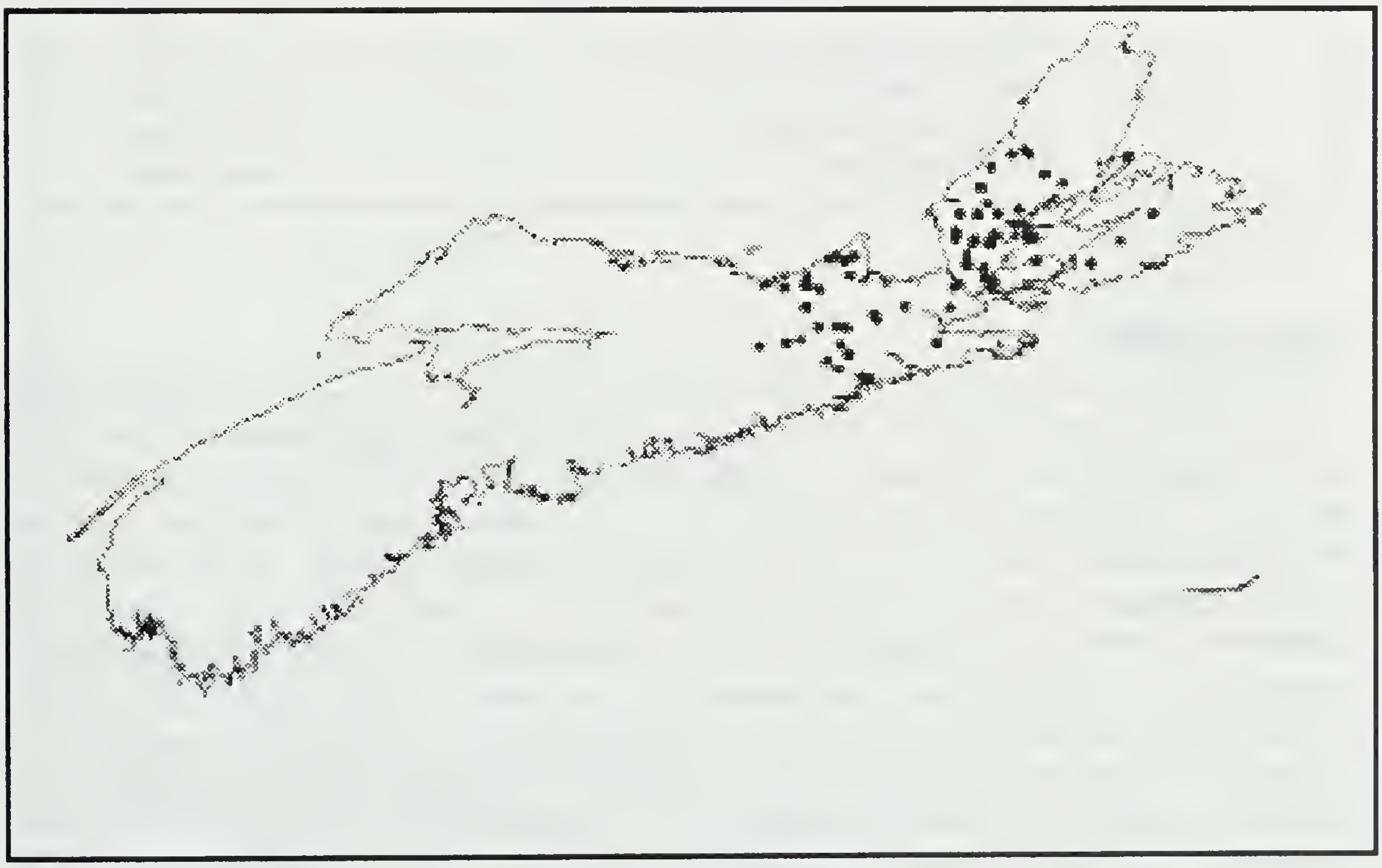

Fig 2 Stora-owned properties that were selected by the coarse filter analysis for possessing representative or outstanding natural features.

Table 2 Landscapes containing Stora-owned properties and their current representation status.

Landscape (#)	Landscape title	Representation*
22	Northumberland Strait Plain	inadequate
26	Central Rolling Hills	inadequate
35	Eastern Shore Quartzite Plains	partial
38	Guysborough Headlands	inadequate
39	Canso Granite Barrens	satisfactory
40	Aspen Drumlin Plain	inadequate
41	St. Mary's Plain	partial
42	Pictou River Hills	inadequate
43	McArras Brook Dissected Coast	inadequate
44a	Pictou-Antigonish Hills (Pictou)	inadequate
44b	Pictou-Antigonish Hills (Antigonish)	inadequate
45	South River Low Hills	inadequate
46	Mulgrave Hills	satisfactory
48	Bras d'Or Lake Plain	inadequate
49	North Mountain Ridge	partial
50a	Bras d'Or Fault Ridges (Sporting Mountain)	inadequate
50b	Bras d'Or Fault Ridges (East Bay Hills)	inadequate
51	Forchu Hill Cliffs and Beaches	satisfactory
52	Barren Hill Drumlins	inadequate
54	Mira River Hills and Ridges	inadequate
56	Sydney Plain	inadequate
58	Skye River Hills and Valleys	inadequate
59	Judique Plain and Hills	inadequate
61	Western Cape Breton Coastal Plain (Inverness)	inadequate
62	Masons Mountain	inadequate
63	Keppock Mountain	satisfactory
64a	Cape Breton Boreal Plateau (Gillanders Mountain)	inadequate
64b	Cape Breton Boreal Plateau (Central)	satisfactory
65	Margaree-Middle River Valleys	inadequate
68	Interior Steep Slopes	satisfactory
69	Central Cape Breton Hills	inadequate
70	Kelly's Mountain	inadequate

* Source: (DNR 1994a)

Representation

Stora-owned properties are located within twenty-nine of Nova Scotia's eighty natural landscapes (Table 2). Since three of these landscapes contain sub-units, in total, thirty-two distinct biogeographical land units were assessed by the coarse filter analysis. Most Stora-owned properties are located within landscapes currently underrepresented with publicly-owned protected areas (Table 3). Of the thirty-two distinct land units containing Stora properties, for instance, six were satisfactorily represented (19%), none near-satisfactorily represented (0%), three partially-represented (9%), and twenty-three inadequately represented (72%) (Fig. 3). Thus, a Stora-owned system of nature reserves is well positioned to fill representation gaps existing within the publicly-owned system of protected wilderness sites, since most of its candidate reserves occur within inadequately represented landscapes.

Several underrepresented landscapes, in particular, could benefit from the implementation of a Stora-owned system of nature reserves (Fig. 4, Table 4). The inadequately represented Bras d'Or Lake Plain (#48), Skye River (#58), and Judique

Table 3 Stora-owned properties per landscape.

Landscape (#)	Stora properties	Representation*
22	P15, P16, P17, P18, P19	inadequate
26	P1	inadequate
35	G1, G3, G10, G11, G14	partial
38	G11, G12, G13	inadequate
39	G14	satisfactory
40	G2, G4, G6	inadequate
41	P2, P3, P4, P5, G1, G2, G5	partial
42	P6, P7, P16	inadequate
43	P60, P63, P64	inadequate
44a	P8, P9, P10, P11, P12, P13, P14, P20, P21, P22, P23, P24, P62, P63, P65, P66, P67	inadequate
44b	P55, P56, P57	inadequate
45	P25, P26, P27, P28, P30, P31, P32, P33, P34, P35, P36, P37, P38, P39, P40, P41, P42, P43, P44, P45, P46, P47, P48, P49, P50, P51, P52, P53, P54, P58, P59, P61, G8, G19	inadequate
46	P29, G6, G9, G15, G16, G17, G18, G19, G20, G21, G22, G23, G24	satisfactory
48	C8, C9, C10, C11, C12, C13, C14, C15, C16, C17, C18, C20, C21, C22, C23, C42, C43, C44, C45, C46, C47, C48, C49, C50, C51, C52, C55, C56	inadequate
49	C53, C54	partial
50a	C7, C8	inadequate
50b	C2, C3, C4	inadequate
51	C5	satisfactory
52	C5, C6	inadequate
54	C1	inadequate
56	C1	inadequate
58	C19, C23, C24, C25, C26, C27, C40, C41, C42, C62, C63, C70, C71, C74, C75, C76, C77	inadequate
59	C19, C24, C25, C26, C27, C28, C29, C30, C31, C32, C33, C34, C35, C36, C37, C38, C39, C40, C41, C61, C64, C65, C66, C67, C68, C69, C70, C71, C72, C73	inadequate
61	C77	inadequate
62	C78, C79, C80	inadequate
63	C57, C58, C59, C60, C61, C81, C82, C83, C85	satisfactory
64a	C83	inadequate
64b	C86, C87, C88, C92, C93, C94	satisfactory
65	C80, C81, C82, C84, C85, C86	inadequate
68	C86, C87, C88, C94	satisfactory
69	C87, C88, C89, C90, C91, C92, C94	inadequate
70	C95	inadequate

*Source: (DNR 1994a)

Plain natural landscapes (#59), for example, each contain over a dozen land holdings identified by the coarse filter analysis as maintaining ecologically significant features. Likewise, the inadequately represented landscapes of Pictou-Antigonish Hills (Pictou subdivision) (#44a) and South River Low Hills (#45) also contain several important properties identified by the coarse filter analysis. Thus, the implementation of a Stora-

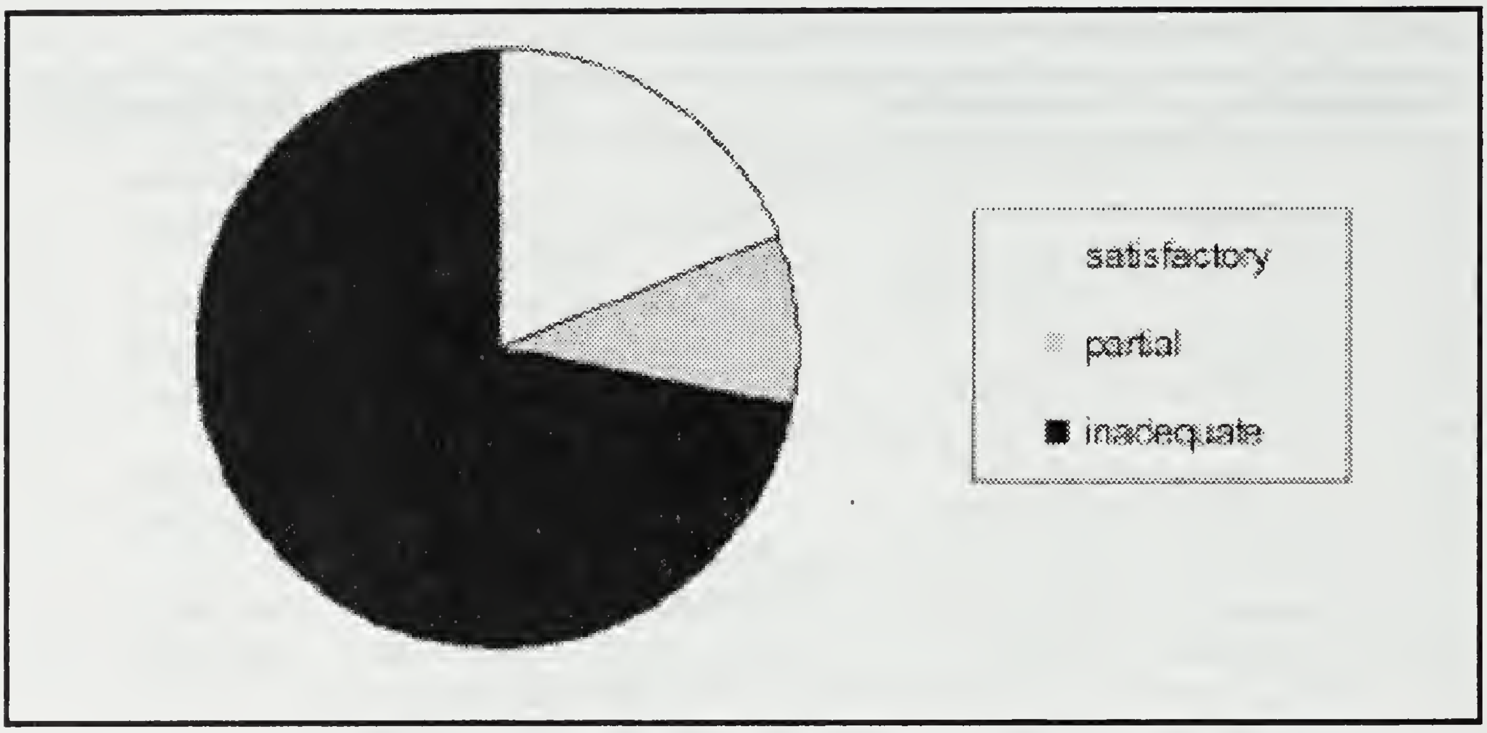

Fig 3 Protected area representation for landscapes containing Stora-owned properties; 72% inadequately represented; 9% partially represented; 0% near satisfactorily represented; 19% satisfactorily represented.

owned system of nature reserves could help advance representational targets in Nova Scotia for several key landscapes currently underrepresented with publicly-owned protected sites.

Properties C80 and C95 are particularly important to a Stora-owned system of nature reserves, since these land holdings occur within two of the smallest underrepresented landscapes in Nova Scotia: Masons Mountain (#62) and Kelly's Mountain (#70). Because these landscapes are so small, approximately 8500 ha and 11500 ha respectively (DNR 1997), the designation of properties C80 and C95 as nature reserves could unilaterally advance representation targets within these two landscapes. In the case of Kelly's Mountain, for instance, property C95 (819.9 ha) accounts for approximately 7% of the entire landscape. Its protection would fill an important gap within the existing system of protected wilderness sites within the province.

Outstanding Features

Fifty-nine of the one hundred eighty-six Stora-owned parcels of land were identified as containing one or more outstanding natural features (Table 5). Thirty-nine are located on Cape Breton Island, ten in Guysborough County, six in Antigonish County, and four in Pictou County. Outstanding natural features identified by the coarse filter analysis include old-growth forest, old forest, climax forest, significant wetlands, significant floodplains, talus slopes, ravines, headwaters, lakeshores, lake islands, lagoons, ephemeral rivers, oxbow lakes, coastal zones, tidal areas, limestone regions, and mountain barrens. In addition to these features, literature reviews also flagged sixteen properties as potentially containing rare or threatened species.

Given the scarcity of old-growth forests in Nova Scotia (e.g. Lynds 1992, DNR 1994b), all forty-one Stora-owned properties found to possess old forest systems were considered ecologically important. A number of different forest types were identified, including a combination of deciduous, coniferous, and mixed forest stands. Most properties containing old growth forest were found to occur on Cape Breton Island. This may be an artifact of the aerial photograph analysis, since these properties were examined using older photographs than those used for properties on mainland Nova

Table 4 Stora-owned properties per landscape that were selected by the coarse filter analysis as candidate protected sites.

Landscape(#)	Stora properties	Representation*
22	P16	inadequate
26	P1	inadequate
35	G1, G3, G10, G11, G14	partial
38	G11, G12, G13	inadequate
39	G14	satisfactory
40	G2, G4	inadequate
41	G1, G2, G5	partial
42	P16	inadequate
43	P63, P64	inadequate
44a	P8, P9, P20, P24, P63, P65, P66, P67	inadequate
44b	P55	inadequate
45	P28, P30, P58, P59, P61, G19	inadequate
46	P29, G15, G19, G22, G23	satisfactory
48	C10, C11, C12, C14, C21, C22, C23, C43, C45, C46, C47, C48, C50, C55, C56	inadequate
49	C54	partial
50a	C7	inadequate
50b	C3, C4	inadequate
51	C5	satisfactory
52	C5, C6	inadequate
54	C1	inadequate
56	C1	inadequate
58	C19, C23, C24, C25, C26, C40, C41, C62, C63, C70, C74, C75, C76, C77	inadequate
59	C19, C24, C25, C26, C34, C39, C40, C41, C65, C66, C67, C68, C69, C70,	inadequate
61	C77	inadequate
62	C80	inadequate
63	C57, C58, C59, C60, C82, C83	satisfactory
64a	C83	inadequate
64b	C86, C88, C94	satisfactory
65	C80, C82, C86	inadequate
68	C86, C88, C94	satisfactory
69	C88, C94	inadequate
70	C95	inadequate

* Source: (DNR 1994a)

Scotia. Later stages of this project may reveal that several of these sites may no longer exist in an old growth forest condition and the reserve system will have to be adjusted accordingly.

Several of Stora's properties were found to contain important wetland systems, including examples of bogs, fens, riparian zones, and shallow open-water areas. In addition to the important habitat that these systems provide, wetlands also perform a number of crucial ecological services, including water purification, groundwater regulation, temperature modification, and sedimentation control, among others (e.g. Mitsch & Gosselink 2000). The most significant wetlands identified by this analysis were found on properties C14, C55, C56, and G11.

Properties located along the St. Mary's River in Guysborough and Pictou Counties, and the River Denys south of the Bras d'Or Lakes on Cape Breton Island, were assigned

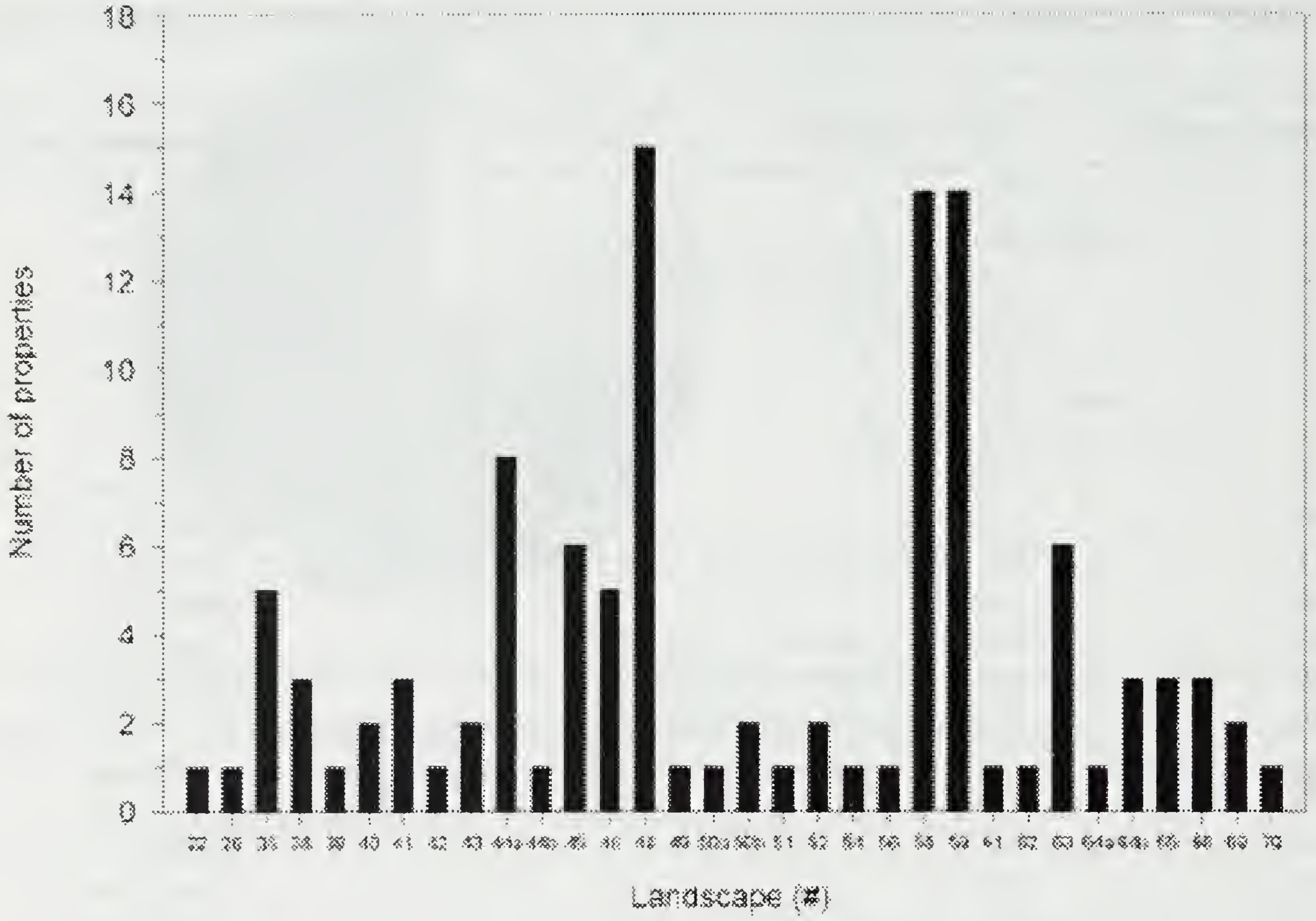

Fig 4 Stora-owned properties per landscape that were selected by the coarse filter analysis. Landscape numbers refer to titles presented in Table 2.

a high level of conservation importance given the ecological significance of these waterways. The St. Mary's River contains one of the highest concentrations of wood turtles (*Clemmys insculpta*) in the province, a species classified by the Committee On the Status of Endangered Wildlife in Canada as being of special concern for conservation (COSEWIC 2001). The rare eastern pearlshell (*Margaritifera margaritifera*) and brook floater (*Alasmidonta varicosa*) freshwater mussels also occupy the river, and its riverbanks maintain patches of old-growth forest and important intervale habitat. Likewise, the River Denys is significant for its forested floodplains, rare intervale flora, karst topography, and for a small breeding population of wood turtles. Properties G1, G3, G5, and P8 maintain shoreline frontage on the St. Mary's River, while C45, C46, and C47 occur along the River Denys.

Likewise, properties located along the shores of the Bras d'Or Lakes on Cape Breton Island were also assigned a high level of conservation importance. This 260 km^2 brackish water body, sometimes referred to as an inland sea or estuary, is naturally connected to the ocean via two restricted channels and one man-made canal system (Davis & Browne 1996, Petrie & Raymond 2002, Shaw et al. 2002). It maintains a rich diversity of coastal barriers (Taylor & Shaw 2002), as well as several ecologically significant and disjunct estuarine communities (Davis & Browne 1996, Lambert 2002). Properties C55 and C56 were found to possess shoreline frontage on the Bras d'Or Lakes. They maintain a number of important natural features of importance for protection, including beaches, lagoons, lake islands, significant wetlands, and old forest.

Adjacent protected areas

Large protected areas are better able to support minimum viable populations, perpetuate large-scale natural disturbance regimes, and facilitate long-term changes in

Table 5 Stora-owned properties found to maintain outstanding natural features.

Outstanding feature	Properties
old forest	C10, C11, C12, C19, C21, C25, C26, C34, C39, C40, C41, C43, C45, C48, C54, C55, C56, C57, C62, C65, C66, C67, C68, C70, C76, C80, C82, C83, C86, C95, G2, G3, G4, G23, P1, P12, P61, P63, P64, P65, P67
significant wetland	C14, C55, C65, C95, G11
significant floodplain	C3, C14, C21, C22, C46, C47, C61, G1, G3, G5, P8, P30, P55, P61
talus slope	C95
ravine	C66, P61, P65
headwater area	C76, C95
lake shoreline	C55, C56, G23
lake island	C55, G23
lagoon	C55, C56
beach	C55, C56
ephemeral river	C14
oxbow lake	C14
coastal frontage	C95
tidal influence	C14, C95
frontage on significant waterway	C45, C46, C47, G1, G3, G5, P8
frontage on the Bras d'Or Lake	C55, C56
limestone area	C21, C22, C45, C46, C47, C48, C50, C54, C56, C75, C76
mountain barren	C95
rare species habitat	C14, C19, C21, C22, C45, C46, C47, C74, C95, G1, G3, G5, G12, G13, P8, P30

the natural environment due to climate change than are small protected areas (e.g. Diamond 1975, IUCN 1980, Peters & Darling 1985, Newmark 1987, 1995, Grumbine 1990, Noss 1991, Baker 1992, Caughley & Gunn 1996, Beazley 1997, Meffe & Carroll 1997). In Nova Scotia, however, most publicly-owned reserves are widely scattered and relatively small by comparison with the norm in Canada. Only two areas of the province have protected areas exceeding 100 000 ha of concatenated protected space. These are (1) Kejimkujik National Park/ Tobeatic Wilderness Area, and (2) Cape Breton Highlands National Park/ Pollets Cove - Aspy Fault Wilderness Area. Thus, Stora-owned properties located adjacent to, or near, existing protected areas were considered important inclusions for a nature reserve system because they could effectively expand the size of existing core reserves.

Property G15 is positioned adjacent the 5 720 ha Ogden Round Lake Wilderness Area in Guysborough County, while property C86 is adjacent the 5 471 ha Middle River Wilderness Area in the Cape Breton Highlands. Properties C39, C40, and C41 are located near the Bornish Hills Ecological Reserve; C58, C59, and C60 near Trout Brook Wilderness Area; C88 near Middle River Wilderness Area; C94 near North River Wilderness Area; G14 near the Bonnet Lake Barrens Wilderness Area; and G3 near both the Big Bog Wilderness Area and the Melrose International Biological Programme (IBP) site.

Ecologically significant properties

Several properties examined by this analysis possess more than one significant feature of importance to a Stora-owned system of nature reserves, including both representative and outstanding natural phenomena. Six of these properties, in

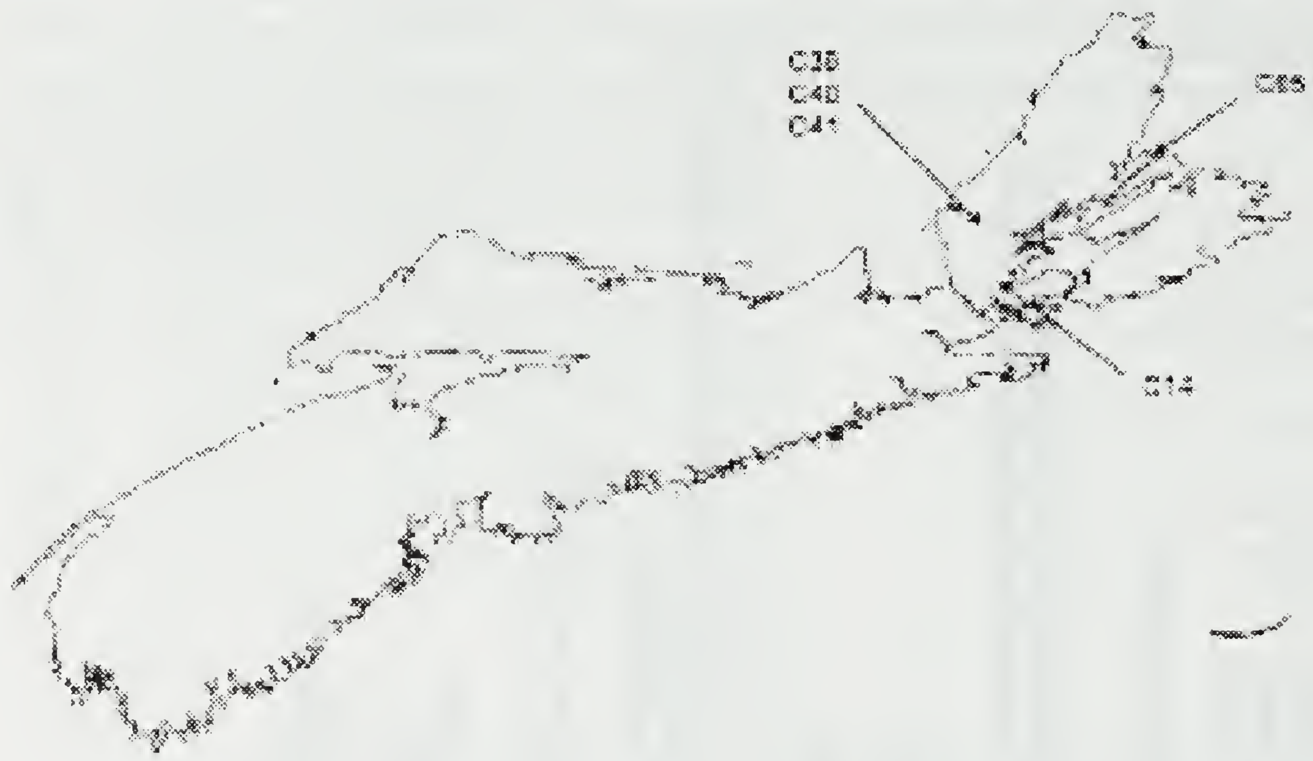

Fig 5 Locations of specified Stora land holdings.

particular, are of greatest importance for protection, including properties C14 and C95 individually, and properties C39, C40, and C41 together as a conglomerate (Fig. 5). These land holdings are described below.

Property C14 Located midway between Port Hawkesbury and the southern extremity of the Bras d'Or Lakes, property C14 contains one of the largest remaining undisturbed floodplains in Nova Scotia. This 680 ha property is characterized by a wetland - dwarf spruce complex with several examples of ephemeral rivers, oxbow lakes, small lichen-dominated barrens, and several rare taxa. It is also significant for its representation potential, as it occurs within the inadequately represented landscape of the Bras d'Or Lake Plain.

Property C95 The largest land holding assessed by this analysis was property C95. It is 819.9 ha in size and covers much of the northeastern side of Kluscap Mountain, otherwise known as Kelly's Mountain. This land holding registered the highest number of outstanding natural features on a Stora-owned property, including features such as old-growth hardwood forest, old-growth mixed forest, old-growth hemlock forest, wetland complexes, coastal frontage, mountain barrens, talus slopes, exceptional geologic features, and a diverse habitat mosaic characteristic of the Kelly's Mountain natural landscape. The entire mountain is also sacred to the Mi'qmak people as the birthplace of Kluscap and traditional native ceremonies are sometimes performed nearby, at the entrance to the Fairy Hole Cave at Cape Dauphin. Property C95 is also well positioned to fill a gap within the relatively small, but inadequately represented landscape of Kelly's Mountain. Since Crown lands adjacent to property C95 are also under consideration for protected status (DNR 1996), this land holding has the added potential of becoming a constituent of a nature reserve conglomerate.

Properties C39, C40, and C41 The closely positioned land holdings of C39, C40, and C41 are located within the inadequately represented Skye River and Judique Plain natural landscapes. These properties, together as a cluster, maintain a total cumulative area of 1185 ha, nearly 5% of the total area of all privately-owned Stora land holdings. Together, they possess a representative expanse of old-growth Acadian hardwood forest continuous with the nearby, publicly-owned Bornish Hills Ecological Reserve. This makes the concept of connectivity (e.g. Soulé & Simberloff 1986, Simberloff & Cox 1987, Hudson 1991, Noss & Cooperrider 1994, Caughley & Gunn 1996, Primack 1998, Beazley et al. 2004) particularly relevant for properties C39, C40, and C41, since these land holdings could be interconnected with wilderness corridors that extend to include the Bornish Hills Ecological Reserve. This would help establish a relatively large protected area within a region of the province severely fragmented with clearcuts and logging roads.

Future work: fine filter analysis

The coarse filter analysis presented in this paper identified sixty-eight of the one hundred eighty-six Stora land holdings as areas from which protected areas can eventually be selected. Later stages of the project will further reduce this number to ensure that the most significant Stora-owned properties are the ones actually chosen for protection. This could be achieved using a fine filter analysis (see: Noss 1987, Hunter et al. 1988, Noss & Cooperrider 1994), which would involve field-verifying the results of the coarse filter analysis presented here, and collecting site specific baseline data on features such as topography, bedrock geology, geomorphology, habitat-types, stand structures, and species compositions, among others. Land holdings still found to maintain important representative or outstanding natural features would then be designated as nature reserves.

To prioritize reserve designations, properties could be scored quantitatively using a set ranking procedure (see: Noss 1993, DNR 1994a). This may involve scoring properties for a variety of phenomena, including representation, outstanding natural features, wilderness value, and rare species, among others. These categories could also be differentially weighted to give preferences to Stora-owned properties with specific natural features best addressing the conservation objectives of the fine filter analysis. Properties receiving the highest scores would then be considered the highest priority for protection.

In order to prevent the degradation of candidate protected sites between their initial coarse filter identification and such time as they can be formally established as nature reserves, interim protection should be afforded those sites deemed most ecologically significant. Quickening the pace of reserve designations would also limit the risk of degradation by shortening the time period in which candidate protected areas remain in an interim state.

Conclusions

Sixty-eight of the one hundred eight-six Stora land parcels examined by this analysis were found to maintain sufficient representational features or outstanding natural phenomena to be considered candidate reserves for the establishment of a protected area system. Since most of these properties occur within landscapes that are inadequately represented with existing protected sites, a Stora-owned system of nature reserves is well positioned to help fill significant representational gaps in the provincial network of publicly-owned protected wilderness areas. Several of the examined properties were also found to maintain outstanding ecological features of provincial significance, including one of the largest undisturbed floodplains in Nova Scotia, several assemblages of intact old-growth Acadian forest, and important habitat for rare or threatened species. Others were located along significant waterways or positioned adjacent to existing protected wilderness areas.

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Volume 42, Part 2, pp. 409-410

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Purpose

To provide an opportunity for students to have their work recognized by a scientific society and to have it considered for publication in a peer-reviewed scientific journal.

Eligibility

The competition is open to any student currently enrolled in a degree program at a recognized educational institution.

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Three broad categories for competition:

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Life Sciences	e.g. animal and plant cell biology, medical sciences, biochemistry, physiology etc.
Physical Sciences	e.g. physics, chemistry, engineering, mathematics, computer science etc.

Three undergraduate prizes are available in each of these three categories:

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For an article written by a student in a nonscientific discipline.
Subject must be relevant to science in Nova Scotia.
Single prize of $200 plus one year's membership to NSIS.

The Graduate Student Prize was awarded jointly to:

Tammy Estabrooks
MSc Student Biology
Saint Mary's University
for
"Gene expression during indirect somatic embryogenesis of plants"

and

Bhavleen Kaur
PhD Student Biological Engineering
Dalhousie University
for
"Ultrastructure and characteristics of a deep-sea bacterium"

The Scientific Writing Prize was awarded to:

Laura Pellerine
3rd Year Journalism Student
University of King's College
for
"Bugs, an investigative tool: a look at forensic entomology"

PROC. N.S. INST. SCI. (2004)
Volume 42, Part 2, pp. 411-419

2003 NSIS Graduate Student Prize Winning Paper: Joint Award

GENE EXPRESSION DURING INDIRECT SOMATIC EMBRYOGENESIS OF PLANTS

TAMMY ESTABROOKS* and ZHONGMIN DONG
Department of Biology
Saint Mary's University
Halifax, Nova Scotia

Somatic embryogenesis is the process by which somatic cells are induced into an embryogenic state, followed by differentiation into embryos. Somatic embryogenesis, in addition to being a method of propagation, can serve as an experimental tool for research into plant embryo development. This is a review of the current literature on *in vitro* plant somatic embryogenesis and the molecular advances made to identify genes expressed during the various stages of this process. Some factors hindering the elucidation of the molecular mechanisms underlying somatic embryogenesis are discussed.

L'embryogenèse somatique est le processus par lequel les cellules somatiques passent à l'état embryogène et se différencient en embryons. En plus de constituer une méthode de propagation, elle peut servir d'outil expérimental de recherche pour développer des embryons de plantes. Le présent document est une revue de la documentation sur l'embryogenèse somatique végétale *in vitro* et sur les progrès réalisés à l'échelle moléculaire pour identifier les gènes exprimés au cours des divers stades du processus. On examine aussi certains facteurs qui rendent difficile l'élucidation des mécanismes moléculaires de l'embryogenèse somatique.

Introduction

Plants are multicellular organisms, composed of highly organized tissues and organs. Plant development, like that of all multicellular organisms, involves the differentiation of cells such that they "acquire distinct metabolic, structural and functional properties" (Taiz & Zeiger 1998). Plant cells differentiate into either sexually reproductive cells or somatic (asexual) cells. Sexually reproductive cells are responsible for the production of a new generation; the fusion of male and female gametes involves the recombination of genetic information through meiosis. This genetic mixing results in offspring that are genetically different from the parent plants. Genetic diversity provides plants with a selective advantage helping to ensure survival of the species during environmental change.

Somatic or asexual cells have two distinct functions: 1) vegetative growth and 2) asexual reproduction. Vegetative growth involves the increase in plant cell size and number. During their lifespan, plants must continuously generate new tissues and organs, for example, to repair the damage caused by herbaceous animals. Asexual reproduction involves the production of plants genetically identical to the single parent plant, a process also known as cloning. Asexual reproduction allows plants to reproduce when the costs of sexual reproduction are too high, environmental conditions are not suitable for sexual reproduction or in cases where individuals may be isolated, in terms of distance, from other individuals. Plants are capable of asexual reproduction and regeneration of lost parts as a result of the totipotent nature of their

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* Author to whom correspondence should be addressed.

Key words: somatic embryogenesis; totipotency; plant tissue culture; gene expression

cells. Many plant cells are totipotent, meaning that under appropriate conditions, they are able to differentiate into "the entire spectrum of cell types" found within the plant (Weigel & Jürgens 2002).

For most animal cells, the differentiation process is irreversible while plant cells have the unique ability to *de*differentiate. Upon dedifferentiating, plants can access the genetic information for the entire genome and therefore regain the undifferentiated or embryonic state. Given the sessile state of plants, this ability to "adapt their programme of differentiation and growth" is an important survival mechanism (Roberts et al. 2002). This survival mechanism is evident in a plants' ability to grow back lost parts consumed by animals.

The abilities of plants to reproduce asexually and plant cells to dedifferentiate have been used in plant propagation through plant tissue culture. Plant tissue culture is a broad term referring to the growth of plant cells, tissues or organs under sterile conditions in culture (*in vitro*). One process carried out through plant tissue culture is that of somatic embryogenesis (SE). SE is the development of bipolar embryos from somatic cells and tissues; bipolar meaning they possess both a shoot and a radical end (Sharp et al. 1980). Somatic cells are induced to dedifferentiate and are then reprogrammed to develop into bipolar embryos. The embryos produced via SE, referred to as somatic embryos, are capable of developing into complete plants. The embryos are produced asexually; therefore the resulting plants are genetically identical to the tissue from which the embryos were derived. Although somatic embryogenesis has been reported to occur naturally in species of *Bryophyllum* (Yarbrough 1932) and *Malaxis* (Taylor 1967), it is best known as a pathway used in plant tissue culture to propagate plants. The first report of somatic embryogenesis *in vitro* was in carrot (*Daucus carota* L.) (Steward et al. 1958). The fact that the embryos are bipolar is ideal for propagation in that it allows for simultaneous root and shoot formation. In addition to being a method of propagation, SE is a valuable tool for studying zygotic plant embryo development, which is a difficult task given the intact nature of plant seeds.

Somatic Embryogenesis

General

There are two types of somatic embryogenesis: direct and indirect. Direct SE refers to the process of inducing somatic embryos or embryogenic tissue directly from the differentiated tissue. Zygotic embryos are one of the most successful sources of initiating direct SE (Merkle et al. 1990). Quite often however, the objective of SE is to clone a mature plant after its characteristics and performance have been evaluated and found to be desirable. This objective is especially true of plants whose economic market is driven by consumers' demands for specific floral forms and horticultural traits such as disease resistance (Marchant et al. 1996). Zygotic embryos cannot be used to clone a mature plant since they are produced sexually and therefore are genetically different from the plant that produced them. To clone a mature plant, tissues from the plant itself must be used to induce somatic embryogenesis. Somatic tissues exposed to a high concentration of the plant growth regulator, 2,4-dichlorophenoxyacetic acid (2,4-D) have been reported to undergo direct somatic embryogeneis (Kitamiya et al. 2000). The use of somatic tissues for inducing direct SE is hampered by the fact that not all species are capable of this and that high concentrations of 2,4-D cause genetic mutations that encumber the objective of clonal propagation (Swartz 1991).

Most somatic tissues require a "genetic activation" in order to enter an embryogenic state and be capable of producing embryos. Indirect SE involves an intermediate stage prior to somatic embryo or embryogenic tissue formation. Indirect SE has been induced using somatic tissue in several species, such as African violet (*Saintpaulia ionantha* Wendl.) (Mithila et al. 2003), grape (*Vitis vinifera* L.) (Das et al. 2002), rose (*Rosa* sp.) (Ibrahim & Debergh 2001, Kintzios et al. 1999, de Wit et al. 1990), sunflower (*Helianthus maximiliani* Schrader) (Vasic et al. 2001), and Siberian ginseng (*Eleutherococcus senticosus*) (Choi et al. 1999). The goal is to induce the source tissue (explant) to dedifferentiate and form callus; a mass of unorganized cells (Figure 1). The callus is not yet committed to differentiate into any organized structure and must be further "genetically activated" to produce embryos. It has been reported that the initiation of embryogenic tissue from differentiated explants often involves "extensive proliferation through an unorganized callus cycle" (Merkle et al. 1990). Factors reportedly used to activate callus growth include growth regulators, such as auxins (Murashige & Tisserat 1977), stress such as starvation of the tissue (Lee et al. 2001), and heat shock. Frequently, exposure to a low concentration of 2,4-D followed by transfer to an even lower concentration of 2,4-D or growth regulator-free medium has been successful in inducing SE in a wide range of plant species, as in Siberian ginseng (*Eleutherococcus senticosus*) (Choi et al. 1999), rose (*Rosa* sp.) (de Wit et al. 1990), oat (*Avena sativa)* (Chen et al. 1994), and carrot (*Daucus carota)* (Toonen et al. 1994). The removal of 2,4-D is not believed to be responsible for initiating SE however it allows the progression of the pre-embryonic cells to the advanced stages of somatic embryo development.

The structural characteristics of embryogenic cells are typical among many species; consisting of small cells with dense cytoplasmic contents, small vacuoles and large nuclei with very distinct enlarged nucleoli (Williams & Maheswaran 1986). The external morphology of both callus and embryogenic tissue varies greatly amongst and within plant species (Rout et al. 1999). Toonen et al. (1994) reported high morphological variability among single suspension cells of carrot (*Daucus carota*) that were competent to become embryogenic. This variability makes it difficult to distinguish or predict cells with embryogenic competence even within an individual. Positive identification of embryogenic tissue is sometimes only known by the presence of nodular structures. This nodular tissue is often referred to as proembryogenic masses (PEMs) (von Arnold et al. 2002). The nodular structures are actually early globular stage embryos that precede the later stages of dicotymous embryo development, i.e., heart-shaped, torpedo-shaped and cotyledonary embryos (Figure 2).

Once somatic embryos reach the cotyledonary stage, they must go through sequential stages of maturation, a desiccation or cold period, germination, acclimatization and transfer to in the *ex vitro* environment. There is much diversity among and within plant species in terms of the stages and time lines of SE (Das et al. 2002, Ibrahim & Debergh 2001, Vasic et al. 2001, Kintzios et al. 1999, de Wit et al. 1990). Despite this diversity, it is known that the various stages of SE involve the "commitment of specific cells to a sequential pattern of selective gene expression" (Zimmerman 1993, Giroux et al. 1997).

Gene expression during somatic embryogenesis

Each stage of somatic embryogenesis involves the activation and deactivation of genes. Certain plant developmental processes are likely the result of an array of interacting genes, which require the expression of proceeding genes (Torres-Ruiz et al. 1996). The isolation of embryo-specific genes and the characterization of their roles during embryo development are fundamental in the overall understanding of the molecular processes regulating embryogenesis (Magioli et al. 2001). Understanding

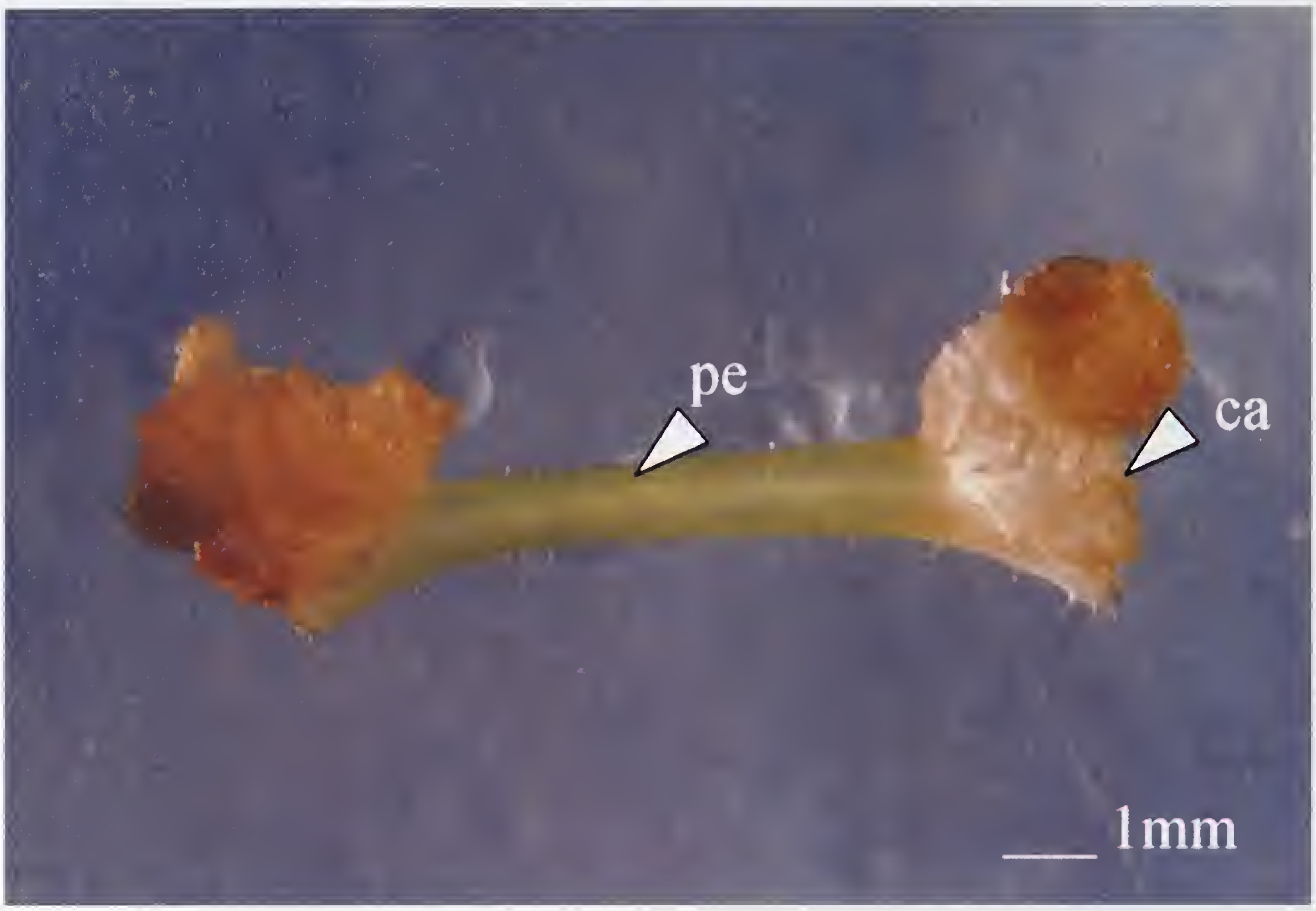

Fig 1 Callus (ca) developed on the excised ends of a rose petiole explant (pe) after two weeks growth on medium containing 5µM 2,4-D.

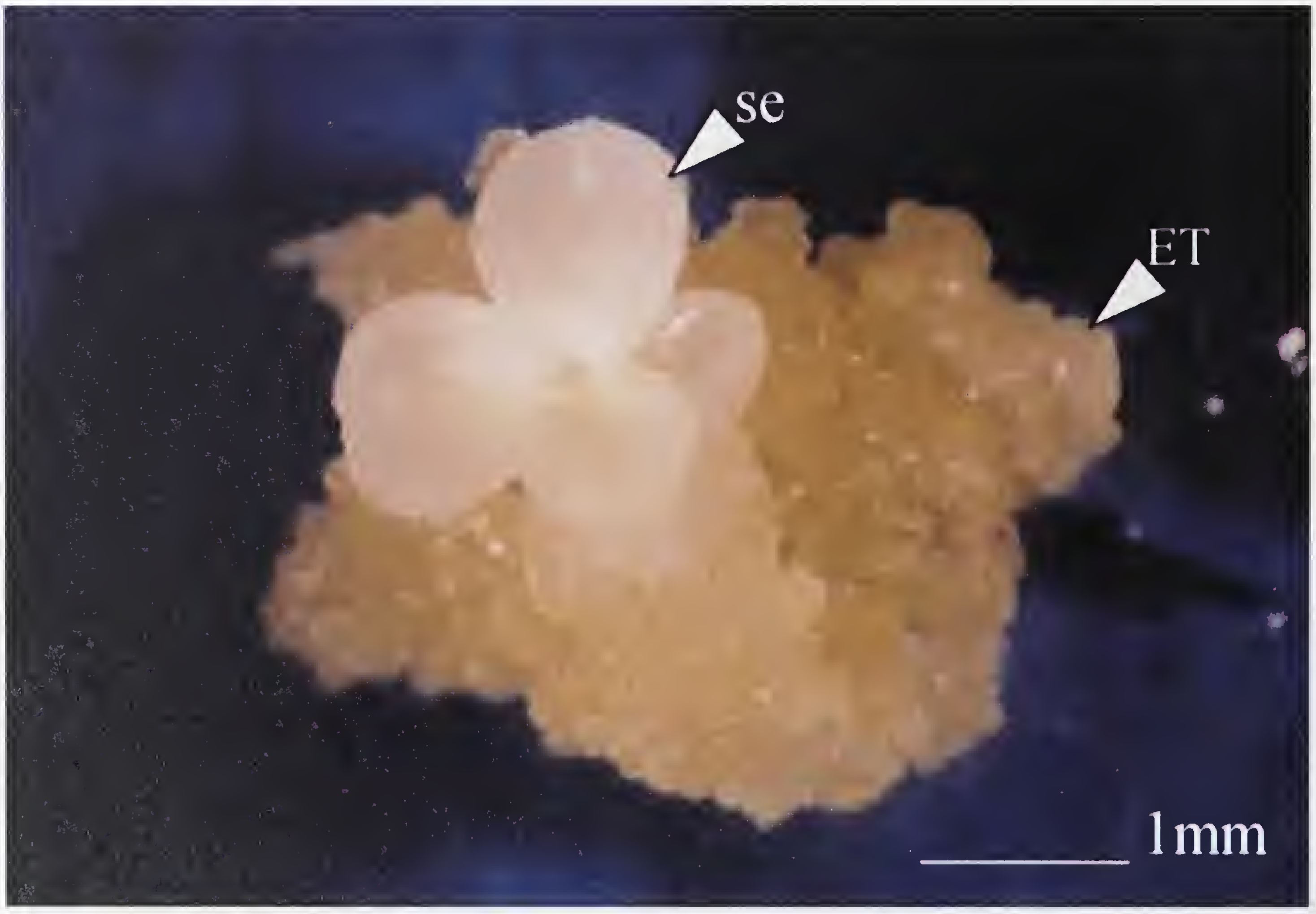

Fig 2 Somatic embryo (se) growing on embryogenic tissue (ET) after transfer of tissue to growth regulator-free medium.

the genetic control of development is one of the most fundamental questions in biology and remains one of the main research areas of molecular biology today.

The first step in indirect somatic embryogenesis is to dedifferentiate somatic cells to form callus. As previously mentioned, exposure to the plant growth regulator 2,4-D is one means of achieving this. Reprogrammed gene expression is evident by the synthesis of new messenger ribonucleic acid (mRNA) after exposing cells growing *in vitro* to 2,4-D (Hagen et al. 1984, Theologis 1986, Van der Zaal et al. 1987). The exact stages and mechanisms involved in the transition of callus cells into embryogenic cells are not known. Quite often the callus induction stage and its subsequent transition to an embryonic state is collectively referred to as early somatic embryogenesis (Kairong et al. 1999, Sato et al. 1995, Momiyama et al. 1995).

Recent studies have attempted to identify differences in gene expression between callus and embryogenic tissue. Duncan and associates (2003) found that tissue with high levels of *globulin-1* (*Glb1*) - protein encoded polypeptides is embryogenically competent. In non-embryogenic tissues, very low concentrations of *Glb1* were detected. The *Glb1* protein is known to be synthesized in zygotic embryos shortly after pollination.

In carrot (*Daucus carota*), the Somatic Embryogenesis Receptor-like Kinase (SERK) gene was found to be a useful marker of single cells possessing competency to form somatic embryos (Schmidt et al. 1997). SERK gene expression was detected in a cohort of slightly elongated and vacuolated cells throughout the developmental stages prior to reaching the globular stage embryos. Somleva and associates (2000) also identified the SERK gene during the induction of "embryogenic cell formation" in single cells of *Dactylis glomerata.*

HBK2, a new gene belonging to class I of the KNOTTED1-like homeobox (KNOX) genes was expressed in Norway spruce (*Picea abies* (L.) Karst.) during proembryogenic masses through to late stage somatic embryo development (Hjortswang et al. 2002). Homeobox genes control cell specification and pattern formation during plant development. The HBK2 gene was expressed only in embryogenic cell lines that resulted in somatic embryo production and not in cell lines that failed to produce embryos. Other related KNOX genes have been reported to be differentially expressed during both zygotic and somatic embryogenesis of maize (*Zea mays* L.) (Zhang et al. 2002).

Kairong and associates (1999) obtained three complementary deoxyribonucleic acids (cDNAs) from early somatic embryogenesis of *Lycium barbarum,* which were not observed in calli. The cDNAs were produced after the transfer of the tissue from 2,4-D to an auxin-free medium. Although the roles of these cDNAs were not discussed, the results of this study support the notion that callus induction and its transition into an embryogenic state are two distinct processes involving the expression of distinct genes. Likewise, Giroux & Pauls (1997) identified three cDNAs transcripts (*ASET1, ASET2,* and *ASET3)* present in embryogenic tissues of alfalfa (*Medicago sativa* L.) but absent in petioles, mature embryos or non-embryogenic tissue.

Several genes expressed during the various stages of somatic embryo development have been identified. New gene products synthesized in plants upon the removal of auxin from the medium were reported by Borkind and associates (1988).. These gene products are required for the transition from globular stage embryos to the heart-shaped stage.

The *CEM6* gene coding for a protein expressed during early embryo development with the highest levels occurring at the early globular stage (Sato et al. 1995) reportedly began to decrease at the later torpedo-shaped stage (Komamine et al. 1999). Magioli and associates (2001) reported the expression of the glycine-rich *Atgrp-5* gene during early embryo development of *Arabidopsis thaliana* and eggplant (*Solanum melongena* L.). *Atgrp-5* was detected in globular and torpedo stage embryos but eventually turned off in later stage cotyledonary embryos.

Several genes expressed during somatic embryo development appear to have characteristics of a class of proteins called Late Embryogenesis Abundant (LEA) proteins (Sunderlíková & Wilhelm 2002, Dure et al. 1981, 1989, Galau et al. 1986). Most of the LEA transcripts increase significantly in somatic embryos at the heart stage (Choi et al. 1987, Wilde et al. 1988, Franz et al.1989, Wurtele et al. 1993). The LEA genes appear to be induced by the application of abscisic acid (ABA) (Hatzopoulos et al. 1990, Goupil et al. 1992) as well as other factors such as water stress (Han et al. 1997). ABA is a growth regulator produced naturally by plants during zygotic embryogenesis and is commonly employed during the maturation stage of SE (von Arnold et al. 2002). Dong & Dunstan (1997) identified five ABA-responsive cDNAs from white spruce (*Picea glauca* L.). Three of the cDNAs (PgEMB12, 14 and 15) were speculated to encode LEA proteins while the other two (PgEMB5 and 23) were not similar to any known DNA or protein sequences. Sunderlíková & Wilhelm (2002) reported the accumulation of mRNAs during the maturation of oak (*Quercus robur* L.) somatic embryos that were similar to that of the LEA proteins observed during late cotyledonary embryos development.

Early molecular studies evaluating gene expression in SE focused mainly on the developmental stages of somatic embryos with little attention being paid to the initiation of somatic embryogenesis (Zimmermann 1993). The fact that somatic embryo development is readily divided into distinct stages based on morphological characteristics (globular, heart-shaped, torpedo-shaped and cotyledonary) makes it an easier task to approach than that of the less well-defined stages of early somatic embryogenesis. Although there are both molecular and morphological differences between non-embryogenic and embryogenic tissue, the transition from one stage to the next is still a very grey area. It is difficult to identify differences in gene expression between stages when the stages themselves are not well defined.

Conclusions

Somatic embryogenesis can be induced by several different factors; plant growth regulators, stress, and heat shock. The fact that there is more than one SE inducer suggests that the transition from a somatic cell to an embryogenic cell may have several different molecular routes, further complicating the task of understanding the molecular basis.

A greater emphasis on characterizing and defining the stages involved from dedifferentiation through to the transition of callus into an embryogenic state is required in order to elucidate the processes involved in indirect SE. The understanding of the stages involved in early SE and their underlying molecular mechanisms are linked; advances in one area will facilitate the understanding of the other.

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ULTRASTRUCTURE AND CHARACTERISTICS OF A DEEP-SEA BACTERIUM

BHAVLEEN KAUR[1*] and HENRIETTA MANN[2]
Departments of [1]Biological Engineering and [2]Civil Engineering
Dalhousie University, Halifax, Nova Scotia

The ultrastructure of a bacterium, isolated from rusticles found on the wreck of the *Royal Mail Steamship (R.M.S.) Titanic*, was studied. The bacterium was rod-shaped, gram-negative and produced circular, off-white, opaque colonies on marine agar. Transmission electron microscopy revealed that the bacterium had a typical gram-negative cell wall structure; the nucleoid region was scattered throughout the cytoplasm and darkly stained inclusions were found in the cytoplasm. Negative staining illustrated the presence of 2-6 peritrichous flagella on the bacterium. This bacterial isolate may be part of transient consortia involved in the formation of the rusticles.

On a étudié l'ultrastructure d'une bactérie, isolée de concrétions de rouille en stalactite provenant de l'épave du *Royal Mail Steamship (R.M.S.) Titanic*. La bactérie, en forme de bâtonnet, était Gram négatif et produisait des colonies circulaires, blanc cassé et opaques sur de l'agar marin. La microscopie électronique à transmission a révélé que la structure de la paroi cellulaire de la bactérie était typiquement Gram négatif; la région du nucléoïde était dispersée dans le cytoplasme, caractérisé par des inclusions foncées. La coloration négative a révélé la présence de 2 à 6 flagelles péritriches. Cet isolat bactérien pourrait faire partie des consortiums transitoires qui contribuent à la formation des concrétions de rouille.

Introduction

In 1985, a group of research scientists led by Dr. Robert Ballard aboard the *Akademik Keldysh* succeeded in locating the site of the *R.M.S. Titanic* wreck. The ship was found in the North Atlantic Ocean at a depth of 3.8 km; it had undergone extensive corrosion and was covered by rusticles (Ballard 1987). The surrounding waters were well-oxygenated at a temperature of about 4°C.

During the *Akademik Keldysh* expedition to the *Titanic* wreck site, in 1991, rusticle samples were retrieved. Preliminary analysis of their structure and rate of formation indicated that these rusticles might be of biogenic origin (Ballard 1987, Stoffyn & Buckley 1992). Later work showed that they are highly complex, porous structures that support a wide range of microbial and higher life forms (Stoffyn-Egli & Buckley 1995, Wells & Mann 1997). Cullimore et al. (2002) reported that rusticular microbes may exist in the form of consortia: associations of microbial species that function synergistically. These consortia may be vital or transient depending upon whether the strains involved in their formation can function independently when removed from the consortium. Attempts have been made to isolate and identify organisms that might be involved in the formation of rusticles. Pure cultures of some of the bacteria from the *Titanic* rusticles have been studied and identified as members of *Leptothrix/Sphaerotilus* genera (Wells 1996).

In an extension of these studies we have used the transmission electron microscope to record the ultrastructure of a bacterium isolated and cultured from a *Titanic* rusticle sample.

Key words: deep-sea bacterium, gram negative, ultrastructure, *R.M.S. Titanic*, rusticles

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[*] Author to whom correspondence should be addressed.

Materials and Methods

Rusticle collection and storage

Rusticle samples were collected during the *Akademik Keldysh* expedition, in 1991, to the *R.M.S. Titanic* wreck site by using the articulating arm of the Mir-2 submersible. They were transferred to plastic collection bags, along with sea water and then transported aseptically to the surface (Low 1991, Stoffyn-Egli & Buckley 1995). Until 1993, they were stored under dark, vacuum-sealed conditions at 4°C at the Bedford Institute of Oceanography, Dartmouth, NS.

Isolation of bacteria

The rusticle sample was aseptically removed from the collection bags and rinsed three times in sterile seawater. The rusticle was then dissected aseptically and a portion removed from the interior used to streak plates of #2216 marine agar medium (DIFCO Laboratories, Detroit) for isolation and enumeration of the heterotrophic, halophilic bacteria found in conjunction with the rusticle. These plates were incubated at 4°C±2°C and the bacterial isolates obtained were cultured and stored in 50% glycerol at -20°C. These stock cultures were sub-cultured periodically to ascertain whether contamination had occurred. In 2000, one of the bacterial stocks was re-cultured on #2216 marine agar and broth for this study. Colonial morphology was described after 24-48 h growth on marine agar. Cultures from the marine broth and agar were examined for general morphology and gram staining reactions (Benson 1998) using a light microscope.

Acidity, temperature and salt-tolerance growth ranges

To establish the range of the bacterium's growth at different pH values, marine broth solutions of pH 4.0, 5.0, 6.0, 7.0, 8.0 and 9.0 were prepared and growth was monitored at 27 °C. The temperature range was determined with marine broth samples kept at 4 °C, 15°C, 27°C, and 37°C. Salt concentrations of 0.26%, 2.2%, 8.0%, 14.5%, 20.0% and 32.0 % (wt/vol) were prepared by adding NaCl to the 0.01 M glucose plus basal salts medium of Vreeland & Martin (1980) to ascertain the salt tolerance limit of the bacterium at 27°C. Bacterial growth in all trials was monitored by recording the optical density at 660 nm using a 4040 Novaspec II spectrophotometer.

Electron microscopy protocol

Bacterial cells were harvested from the late stationary phase by centrifugation at 15000 g for 5 minutes. Primary fixation with 2.5% glutaraldehyde in sodium cacodylate buffer for 2h at 4°C was followed by washing in buffer, then postfixation in 1% osmium tetroxide for 2h, followed by staining in 0.25 - 0.5% uranyl acetate for 24h. The cell preparation was then dehydrated with acetone and embedded in Epon Araldite resin (4.6g Araldite, 6.1g TAAB 812, 11.9g DDSA, 0.5g DMP30). Thin sections were cut using a Reichert Jung Ultracut E ultramicrotome. Silver and gold sections (60-90 nm) were picked up on uncoated copper grids. Double staining was performed using lead citrate for 10 minutes and uranyl acetate for 4 minutes. Sections were observed using a Phillips 300 Transmission Electron Microscope at 60 eV; micrographs were obtained with fine grain positive film and printed on resin coated Kodak paper.

Negative staining

Unfixed bacterial cells were placed on formvar coated copper grids and allowed to settle. The grids were then covered with uranyl acetate stain for 30 secs and excess stain was removed. The grids were air-dried for 10-15 minutes and observed using the transmission electron microscope.

Results

Colony characteristics, morphology and gram staining

On marine agar, the cells produced circular, smooth surfaced, raised, off-white, opaque and glistening colonies. Under the light microscope, the bacteria appeared as long and short rod shaped single cells and also formed chains of 2-6 cells. The bacteria were gram-negative.

Acidity, temperature and salt-tolerance growth ranges

The bacterium showed growth in the pH range from 6.0 to 9.0 and no growth at pH values of 4.0 and 5.0. Maximum growth was observed at pH 8.0 and 9.0. The bacterium grew over the temperature range 4 °C to 37 °C; the maximum occurred at 27 °C. The bacteria showed growth at NaCl concentrations of 0.26%, 2.2%, 8.0%, 14.5% and 20.0% (wt/vol) with no growth at 32% NaCl; at 20% NaCl, the growth was very slow. Maximum growth occurred at NaCl concentrations between 0.26 and 8.0% NaCl.

Ultrastructure

Well-preserved bacterial cells were obtained by the double fixation procedure. At a low magnification (14,000X), transverse, oblique and longitudinal cross sections of the bacterial cells were observed. The bacterium ranged in size from 2-4 µm in length and 0.3-0.5 µm in width.

Three distinct layers were visible in the cell envelope (Fig. 1). The outermost layer, the outer membrane (om) was electron dense and double layered, varying between 8 and 10 nm in thickness. A thick (16-20 nm) lightly stained layer, the periplasmic space (ps), occurred on the inner side of the outer membrane. The innermost layer, the cell membrane (cm) was also electron dense and varied in size from 13-15 nm. These 3 layers are typical of gram-negative cell wall structures.

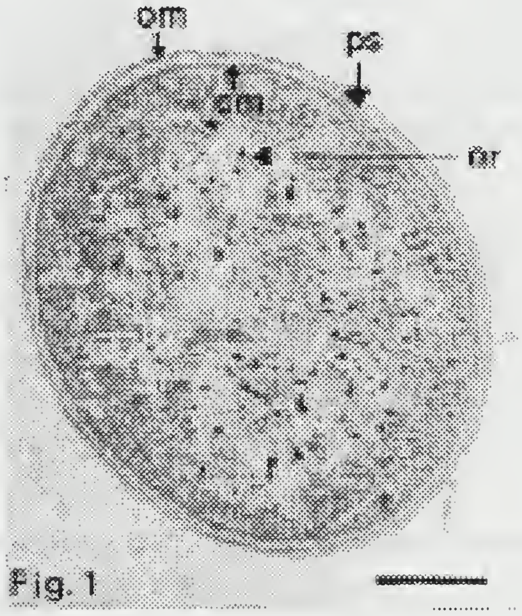

Fig 1 Ultrathin section of the rusticle bacterium showing three distinct layers of the cell envelope: dense outer membrane (om), middle light zone periplasmic space (ps) and inner dense cell membrane (cm). The lightly stained nucleoid region designated nr showing the nucleoplasm containing what may be dense thin DNA fibrils and the cytoplasm containing numerous ribosomes. Bar = 0.2 µm.

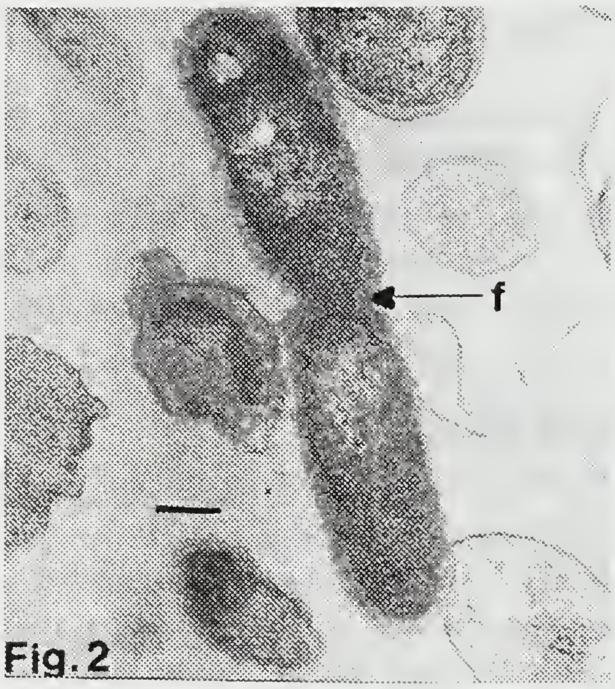

Fig. 2

Fig 2 Thin-section transmission electron micrographs showing cells of the rusticle bacterium undergoing division; note the furrowing (f) of cell envelope. Bar = 0.3 μm

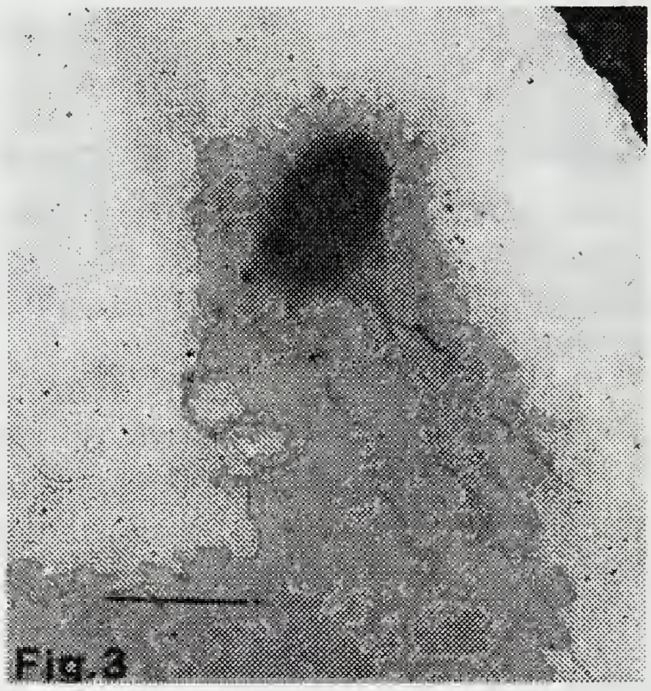

Fig. 3

Fig 3 Negative stained (uranyl acetate) cells of the rusticle bacterium showing flagellar arrangements. The lengths of the flagella varied between 9-12 μm and their diameters ranged between 12-22 nm. Bar = 1.6 μm

The nucleoid region (nr) appeared lightly stained (Fig. 1). It was scattered in the cytoplasm and was not restricted to the center of the cell. Dense and thin fibrils were seen in this region and may represent the deoxyribonucleic acid (DNA). Ribosomes were observed as dark almost circular spots spread throughout the cytoplasm. The size of these ribosomes ranged from 14-18 nm.

Fig. 2 shows a cell which is in the process of cell division. The cell undergoing division was elongated along the longitudinal axis and showed two distinct nucleoid regions. Large numbers of ribosomes were visible in the cytoplasm. Cell division seemed to occur via transverse fission; invagination of the cell envelope appeared to start near the center of the cell and proceed inwards.

Apart from the ribosomes, a large number of darkly stained inclusions of varying sizes were observed in the cytoplasm. Others had a more regular circular or ellipsoid contour; these may be a kind of volutin granule composed of polyphosphate or poly-_-hydroxy butyrate. Histochemical and immunocytochemical tests are needed to determine their molecular composition.

Negative staining

Negative staining illustrated the presence of flagella on the bacterium (Fig. 3); varying numbers of flagella (2-6) were found. These unsheathed flagella were 9-12 μm in length and 12-22 nm in diameter. Some of the flagella had detached and were lying free in the stain. At higher magnification, the points of origin of the flagella were observed and it was found that these were not restricted to any particular region of the bacterial cell. They appeared to arise from lateral and polar ends of the bacterium, i.e. they were peritrichous.

Discussion

The complex structures of the rusticles, found on the *Titanic*, with their goethite-dominated mesh-like matrix, iron-plate like structures, water channels, ducts and thread-like spans, provide various sites with a range of physicochemical conditions suitable for the growth of diverse and site-focused microbes (Stoffyn-Egli & Buckley 1995, Mann 1997, Pellegrino & Cullimore 1997, Wells & Mann 1997). Stoffyn-Egli & Buckley (1995) identified a wide array of mineral precipitates within the rusticles that are stable at very different oxidation-reduction potentials and pH conditions (6.0-8.2). In addition, the restricted flow of water within some of the structures creates higher salt concentrations than occur in the surrounding seawater (Brown 1997). Since the isolate studied has a wide pH and salt tolerance range, it would be able to survive in a number of different formations within the rusticles. The rod-shaped formations covered by lepidocrocite found in the outer surface of the iron-oxyhydroxide shell (Stoffyn-Egli & Buckley 1995, Wells & Mann 1997) are very similar in size and shape to the isolate. They look like solid chains of bacteria with iron deposits around their cells. Furthermore, the *RMS Titanic* rests in highly oxygenated waters that would support this aerobic bacterial isolate.

According to Cullimore et al. (2002), different species within the rusticular consortium perform different activities which support the survival of the consortium and in turn, the growth of the rusticles. Since the isolate studied was successfully cultured in the laboratory, it lends support to the consideration that the rusticles are made by transient consortia containing species that may have arrived via the water column (Simon et al. 2002) or surrounding waters (Takami et al. 1997) and attached to the *Titanic* or the rusticles and helped in their growth.

The halotolerant nature of the isolate studied suggests its suitability for inclusion in a couple of bacterial families: *Halobacteriaceae* and *Halomonadaceae*. Its typical gram-negative cell wall structure and its ability to grow even at low salt concentrations (0.26%) however, precludes its inclusion in the family *Halobacteriaceae*. The family *Halomonadaceae* appears to have more characteristics that are closely related to those of the isolate studied. The type genera for this family, *Halomonas* (Holt 1984), is rod shaped, gram-negative, motile with 4-7 unsheathed lateral or polar flagella, halotolerant, forms white to yellow colonies and is facultatively anaerobic. Our isolate shows most of these characteristics. Thus, while it is possible that this bacterium belongs to the family *Halomonadaceae*, our results are not adequate to show its exact identity.

Conclusion

The isolate studied has characteristics suitable for its survival within the rusticles of the *Titanic*. It may play a role in the formation of these rusticles or it may be a species simply occupying a niche within the structural formations of the rusticles. Further investigation into its characteristics and nutritional capabilities are needed to provide a clearer understanding of the role of this isolate.

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OBITUARY

S.G. Whiteway (1927-2001)

Dr. Stirling G. Whiteway, who died 23 October 2001, was born in 1927 in Stellarton, Nova Scotia. In 1944 he won the Hector McInnes Memorial Scholarship to read science at Dalhousie University, graduating in 1947 after majoring in chemistry. The following year he obtained a National Research Council (NRC) post-graduate bursary and a diploma in chemical engineering. The bursary was extended to 1949 during which he earned the degree of M.Sc. in physical chemistry. He then won a National Research Council overseas science research scholarship to be held under E.K. Rideal at the Royal Institution in London, U.K. but shortly afterwards Rideal moved to Cambridge and Whiteway returned to Canada to work with S.G. Mason at McGill University, where he obtained a National Research Council Fellowship which supported his studies for the degree of Ph.D. He moved to N.R.C. in Ottawa in 1952 to take up a post-doctoral fellow appointment. Shortly afterwards, in 1953, he returned to Nova Scotia to join the National Research Council Laboratory in Halifax. He became Principal Research Officer and was Head of the Industrial Materials Section which managed national programs in coal and ceramic research and included collaboration with industries such as Sydney Steel. He retired from NRC in 1989. Dr. Whiteway was elected to membership in the Nova Scotian Institute of Science (NSIS) in 1947 and was a Life Member. In addition he was a fellow of the Canadian Institute of Chemistry and a member of many other societies including the Canadian Institute of Mining, Metallurgy and Petroleum, American Ceramic Society, Canadian Ceramic Society and Sigma Xi (The Scientific Research Society). He served on Natural Sciences and Engineering Research Council granting committees for six years.

Originally appointed an adjunct Professor at the Technical University of Nova Scotia (TUNS) in 1985 in the Department of Mining and Metallurgical Engineering, he was reappointed in 1990 for consecutive three-year periods, most recently in the Faculty of Engineering (formerly TUNS), Dalhousie University. During this period he taught undergraduate and graduate courses and supervised numerous undergraduate theses.

His first contribution (in association with Professor C.C. Coffin and others) to the NSIS occurred in December 1947 when he demonstrated the experimental measurement of ^{32}P (half-life 14 d, β^{-}1.71 Mev). The technique was used (Proc. N:S. Inst. Sci., 22(3):42) to measure the uptake of the radionucleide by organisms in an acid bog-lake and has been used by molecular biologists ever since. Also under Coffin, in a similar vein, he studied the diffusion of silver nitrate and Ag^{+} in aqueous solution using $^{110}Ag^{+}$ (250 d. β^{-} 0.53 Mev, γ0.9 Mev) as a marker for the cation. This experimental work reveals two of Whiteway's extraordinary skills – his ability to handle safely very hazardous materials and a numerical and algebraic talent – both of which were manifest throughout his career.

His work with Mason at McGill University solved many discrepant results in the literature on the liquid vapour coexistence curves of ethane, ethylene and xenon. It was shown that these discrepancies were mostly due to impurities and agitation. There was therefore good agreement that a major contributor to the "flat-top effect" was gravitational compression.

The very productive collaboration between C.R. Masson and Whiteway in photochemistry, studies of gas-metal systems e.g. the use of levitation to determine the solubility of oxygen in iron at 1800-1900º and the development of a theory of the proportion of oligomers in polymerization reactions were described in Whiteway's contribution to the obituary of C.R. Masson (Proc. N.S. Inst. Sci., 38:189-197), with one notable exception – Whiteway's development of Pascal's triangle for calculating the probabilities of such size distributions. This early example of fuzzy logic (Furuhashi and Uchikawa, 1995) underpinned the intellectual controversies stimulated by Masson, and led to a greater understanding of the chemistry of metallurgical slags.

Whiteway's commitment to public service was exemplified by his contribution to the effort in 1970 by many Canadian scientists and engineers to understand and mitigate the effects of a major spill of "Bunker C" oil into Chedabucto Bay, Nova Scotia.

In the late 1970s Whiteway's interests tended to concentrate on the chemistry of the transformation of coal and iron ore into steel. His description of this chemistry (Proc. N.S. Inst. Sci., 30:67-87) is an authoritative and lucid contribution to our knowledge of the subject and, indeed, the status of the industry in 1980. It would be presumptuous to attempt to summarize this account because it does not necessarily draw attention to the ingenious solutions to the problems of studying chemistry on a laboratory scale at temperatures in the region 1000-2000°. The use of levitation has been mentioned, but not its application to the measurement of the activity coefficients of ferrous oxide in equilibrated iron-ferrous oxide-silicon dioxide melts at ≈1900°. Another notable contribution to high temperature chemistry was the fabrication of ceramic vessels by slip-casting techniques, and studies of their corrosion at elevated temperatures, resistance to thermal shock, abrasion and the relationship between particle size (studied by scanning electron microscopy) and their development of microcracks.

In Whiteway's review of the steel industry he mentions the discovery of transition metal sulfides in coal seams in Cape Breton. Work on these particles (≈20 μm) became part of a general investigation of the changes occurring in the conversion of coal into coke (char). These investigations included the effect of temperature and reduced pressure on the process. The use of "free fall" stainless steel (600 cm high) and quartz (140 cm) reactors was used to determine the production under different conditions of hydrogen, carbon oxides and hydrocarbons. The very complex chemistry of the decomposition of the iron sulfide occlusions was not described in detail. It was shown that the crystalline material (marcasite) was more stable at ≈500° than the pyritic amorphous material and that the sulfur liberated was found partly in the coal tar.

Towards the end of his career, Whiteway returned to problems of diffusion, in particular the diffusion of hydrogen in steel. The subject is of theoretical interest and industrial importance. For example, the mechanical integrity of steel rail used in railroad construction is dependent in part on the hydrogen content of the steel developed during its manufacture. Whiteway and his collaborators constructed an apparatus, fabricated in part from steel rail produced in the mill in Sydney, Nova Scotia, which permitted the study of hydrogen diffusion and "solubility" in steels. It was found for example that the solubility of hydrogen in a steel containing 0.7% carbon, 0.8% manganese and 0.5% silicon at 1000° was 1.9 $\mu g\ cm^{-3}$ and at 770° 0.5 $\mu g\ cm^{-3}$, and that the diffusivity over the same temperature range of the same sample was virtually unchanged at $10^{-3.7}\ cm^2\ s^{-1}$. The figures are given to illustrate the sensitivity and precision of the method which was materially assisted by a general solution of the partial differential equations involved, by Whiteway's son. Whiteway notes in these publications that "the diffusivity of an atom in a solid is a fundamental property which reflects the mobility of the atom and the structure of the host matrix". This fundamental property has become of increasing importance in many fields of chemistry from the diffusion of ions through nafion membranes in the industrial manufacture of caustic soda (Vaughan, 1973; Ramp, 1976), to the migration of activated amino acids in channels of polyribosyl phosphates (Nissen et al., 2000). We must hope that in Pasternak's beautiful words: "(For) others will surely follow/The living imprint of your feet".

For almost 50 years Stirling Whiteway and his wife provided fine hospitality, encouragement and help to many students, post-doctorate fellows and friends, many of whom are now dispersed in different parts of the world. An example of this hospitality and other interests may be found in his last publication in these Proceedings (Proc. N.S. Inst. Sci., 40:59-60). We are proud to have known him and offer our sincere condolences to his wife and family.

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PROC. N.S. INST. SCI. (2004)
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OBITUARY

John Gray Aldous (1916-2002)

Dr. John Gray Aldous passed away peacefully on April 5, 2002 in Halifax. Born on November 16, 1916 in Bristol, England he moved to Canada with his family in 1919 and spent his formative years in Victoria. He attended Victoria College, then part of the University of British Columbia (UBC), and graduated from UBC with a B.A. in 1939 and M.A. in 1941. He completed his PhD in physiology at the University of Toronto in 1945 after investigating the action of narcotics in living cells.

That same year John moved to Halifax with his wife, the former Eileen Hooley of Vancouver whom he had married in 1944. There he took up an appointment as assistant professor in the Department of Pharmacology, Faculty of Medicine at Dalhousie University. His arrival swelled the ranks of the young department to two. Although somewhat nervous in his new appointment because he had never had a course in pharmacology or medicine, he learned quickly through his teaching. He gave the first class in dental pharmacology in 1947, the first undergraduate class in pharmacology to science students in 1950 and was instrumental in establishing the graduate program in pharmacology. Dr. Aldous was promoted to associate professor in 1948, and full professor and Head of the Department of Pharmacology in 1950, a position he held for twenty-five years. During this period, the department expanded markedly and moved from the old Medical Sciences Building into the new Sir Charles Tupper Medical Building. In 1981 he retired and was appointed Professor Emeritus. Throughout his 36-year career with the Department of Pharmacology, Dr. Aldous was a well-respected teacher and administrator who provided strong leadership to Dalhousie University. Mild-spoken and even-tempered, he formed close friendships with many of his students and took great pride in their accomplishments. In honour of his many contributions, the Department of Pharmacology established the Aldous Prize which is given annually to the best student in the undergraduate science pharmacology course.

For many years John Aldous was an active member of the Nova Scotian Institute of Science: Corresponding Secretary in 1948-1951, Vice President in 1954-1956, and President in 1956-1958. In 1953 he published the first cumulative index of the Proceedings of the Nova Scotian Institute of Science (1865 to 1950). In recognition of his many contributions, he was made an Honorary Life Member.

Dr. Aldous was also a member of the Canadian Physiological Society, Pharmacological Society of Canada, Biological Council of Canada, Nova Scotia Commission on Drug Dependency, Nova Scotia Pharmacy Society, Nova Scotia Heart Foundation, Alpha Omega Alpha Honor Medical Society, and Phi Rho Sigma Medical Society. In addition to his many scientific interests, John had a strong love of the out-of-door. He particularly enjoyed the spring fishing trips down the Eastern Shore with his medical colleagues in the Izaak Walton Club immediately after exams were graded. John and his wife Eileen were strong supporters of the music community in Halifax.

Eileen Aldous was killed in a tragic car accident in October 1969 and for many years Dr. Aldous was a widower. Soon after he retired from Dalhousie, he moved to his son's farm in Hants County to take up the life of a country gentleman. In 1985, he re-married and moved to Vancouver where he enjoyed a new life in old surroundings. After the death of his second wife in 1997, he returned to Nova Scotia to spend his final years close to his three children (Joleen Gordon, Peter Aldous and Don Aldous) and their families. A celebration of his life was held in the Great Hall of the Dalhousie University Club on Saturday May 18, 2002. According to his wishes, his ashes have been dispersed at special places in British Columbia and Nova Scotia.

Prepared by his daughter Joleen and her husband Donald C. Gordon.

PROC. N.S. INST. SCI. (2004)
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OBITUARY

William John Dyer (1913-2003)

The scientific community was saddened to learn of the death of Dr. 'Bill' Dyer on September 22, 2003. Dr. Dyer was born October 30, 1913 in Williams Point (near Antigonish) and attended St. Francis Xavier University where he received his Bachelor of Science degree in 1934. Later he was granted a Masters degree (1937) by MacDonald College followed in 1940 by a Ph.D. from McGill University. He worked for a short time for the Department of Agriculture in Ottawa before moving to Halifax in 1940 to join the Atlantic Fisheries Experimental Station of the Fisheries Research Board of Canada (subsequently renamed the Halifax Technological Laboratory). He soon became head of the Biochemistry Department, a position he retained until his retirement in 1974. It is perhaps of interest that he occupied the same office on the second floor of the building at 1707 Lower Water Street, Halifax, during his entire career as a research scientist. Several laboratory directors came and went over his working years, but all recognized the value of Dr. Dyer's research which was supported by the enlightened policies of the Fisheries Research Board of Canada.

In the 1940s and 50s, research at the Halifax Technological Laboratory was focused primarily on cod, then the economic mainstay of the Atlantic fishery. The main concern was how to retain the fresh quality of fillets shipped to inland markets. Dr. Dyer and his group became recognized for their world-class efforts in understanding the post-mortem biochemical changes in fish muscle that contribute to the deterioration of flavour, odour and texture in iced cod and appear eventually in the frozen cod fillets. Dr. Dyer's prolific publications on the subject described laboratory procedures and tests that could be utilized to scientifically monitor quality in iced fish. These tests included detection of such indicators of spoilage as trimethylamine, free fatty acids, protein solubility and hypoxanthine. Much of the knowledge gained was pre-requisite to the establishment of the federal Department of Fisheries' Inspection Service (which relatively recently became part of the Canadian Food Inspection Agency) and was used in the training of its officers. Dr. Dyer and others at the Halifax laboratory maintained a close working relationship with the Fisheries Inspection Laboratory located next door at 1721 Lower Water Street. As the research progressed it was soon realized that seafood quality was not only dependent on post-harvest handling, chilling, bleeding, washing, etc. but that the physiological condition of the fish prior to harvesting was also extremely important. This included recognition of such factors as spawning condition, seasonal feeding patterns and the stresses of catching.

It should be emphasized that Dr. Dyer's research was not confined solely to cod and haddock, but also included studies on several other species such as lobsters, redfish and scallops. For part of his career he was also very active in evaluating the effect of gamma irradiation for fish preservation and the use of polyphosphates in preventing water loss from fillets during transport.

Many more questions arose with the growing emphasis on frozen fish fillets and many will agree that Dr. 'Bill' Dyer became recognized as Canada's 'Mr. Frozen Fish'. World attention became directed toward Dr. Dyer's research at the Halifax Laboratory from such centres as the Torry Research Station in Aberdeen, U.K., the U.S. National Marine Fisheries Service Laboratory in Gloucester, Mass., several research establishments in Japan, plus Canada's own fish processing industry.

At that time most frozen fish products were considered inferior and the fundamental question was: why did freezing not maintain the flavour and texture of fresh and unfrozen products? The pioneering work of Dr. Dyer and his associates established many of the parameters required to inhibit biochemical changes in frozen cod and several other products. These included rapid freezing, maintaining non-fluctuating storage temperatures at least below -18°C, and using non-permeable packaging materials. Biochemical investigations indicated that the development of free fatty acids through hydrolysis of muscle lipids triggered actomyosin denaturation, resulting in a toughening of texture. This work also led to the development in 1959 of the Bligh and Dyer method of extracting lipids from biological tissues which became a 'Citation Classic' and is still used today as a standard procedure throughout the world. In addition, protein studies revealed factors related to the gelling properties of fish actomyosin; these studies were closely followed in Japan and ultimately contributed to the development of surimi and products such as artificial crab legs. Dr. Dyer was well recognized in Japan, and in 1972 the Japanese Fishing Industry sponsored a seven-week lecture tour taking him to many of the major fisheries centres in Japan.

Dr. Dyer was an active member of a number of scientific organizations [the Nova Scotian Institute of Science, the Chemical Institute of Canada (CIC), the Canadian Institute of Food Science and Technology (CIFST), and the Atlantic Fisheries Technologists] and received awards from the United Nations Food and Agriculture Organization, the CIFST, the CIC, the Japanese Society of Fisheries, and the Japanese Society of Heating, Refrigeration and Air-conditioning Engineers. He was a member of the Masonic Order and the Scottish Rite and was the oldest living Past Master of St. Andrews Lodge No. 1 AF&AM where he remained active as Chaplain past his 85th birthday. He was a member of several painting groups in the Halifax area, a hobby he particularly enjoyed during his retirement years.

Dr. Dyer is survived by his wife of 59 years, Francis Elizabeth (Keeping) Dyer, a graduate of Acadia University who also worked for a time at the Halifax Laboratory (1942-1948). Their family includes Edward, Jim, Shirley and Jean and eight grandchildren.

Prepared by E. Graham Bligh with contributions from colleagues and the Dyer family.

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NOVA SCOTIAN INSTITUTE OF SCIENCE
SESSION 2000-2001

President's Address

In the past year the Nova Scotian Institute of Science and especially the NSIS Council has been involved in several useful scientific activities:

- six free public lectures
- two free public panel discussions
- newspaper, radio and TV media
- supporting high school science fairs
- publication of Volume 41 of the Proceedings
- working on four more issues of the Proceedings
- maintaining its library

The details of the speakers, moderators, titles and dates are listed in the Appendix.

Four of the lectures took place, as usual, in the Nova Scotia Museum of Natural History. The other two lectures and two panel discussions took place at Dalhousie University. We thank both of these institutions. Our audiences are steadily increasing; the average audience at the lectures was about 60 and the average audience at the panel discussions was about 120. The audience question period afterwards has usually lasted an hour. Media people from newspapers, radio and TV attended most of our lectures and panel discussions, and several NSIS speakers were heard on radio or seen on TV throughout Nova Scotia and sometimes beyond.

The NSIS Council has worked very hard and well throughout the past year. Besides the hour and a half Council meetings before each of the public lectures and panel discussions, three extraordinary Council meetings took place during the year. Last year we also added to the Council as observers a fourth-year undergraduate student from Dalhousie and one from Saint Mary's Universities. We plan to add to the Council for the coming year a faculty member from the Dalhousie Faculty of Engineering and a high school science teacher.

Expanding the NSIS memberships has been a problem for several years. This past year we have used more methods to do so:

- our Treasurer, David Goble, has been sitting at a small table where people enter the auditorium to attend our public lecture or public panel discussion. There he politely asks persons to fill in a form and give twenty dollars if they are not already a member.
- when people, including the media, called or e-mailed me about our public events I suggested they become NSIS members.
- each person, except for a spouse or a guest, had to be a member before attending this NSIS Annual Dinner and After-Dinner Talk.

At present I do not know precisely how many NSIS members there are.

I am sad to report that Dr. Donald H. Davies died suddenly on 29 May last year. He had been an NSIS Council member for twenty years and was the NSIS Treasurer from 1988 until he died. He was for many years a faculty member at St. May's University, Chemistry Department, and he was a founding member of the chemical company, Chitogenics. He had a sharp mind with a twinkle in his eye, and he often gave us good advice in Council meetings. In Vol. 41 of the NSIS Proceedings there is a detailed obituary of D.H. Davies, Ph.D. and another obituary of D.W. Russell, Ph.D.

There were several problems delaying the latest issue of the Proceedings of the Nova Scotian Institute, but it was published as Volume 41 in February this year. Each NSIS member will receive his/her copy soon. Furthermore, four more issues of the Proceedings are well underway:

- Bras d'Or issue will be printing this summer
- Conservation issue will have all papers in hand by autumn
- Corals issue planned but ownership must be settled
- Marine Sciences issue will be ready for production early in 2001

What a lovely progress! Of course, NSIS will have to provide several thousands of dollars.

Nova Scotia is divided into seven regions for the purpose of Science Fairs for high school students. The NSIS gives an $80 prize to the student with the best Science Fair exhibition in each of the seven regions. If we get a larger membership we might give $100 first prizes and $50 second prizes in the future Science Fairs. Furthermore, the Director of the Fundy Geological Museum in Parrsboro is willing to host a science workshop this month.

At the end of my report I happily thank each and every member of our Council; they worked long and hard throughout the past year. Now I look forward to the next year with Dr. Georgia Pe-Piper as our NSIS President. She has already made several good comments and suggestions about the Institute's future.

7 May 2001
Donald D. Betts
President

Appendix: Lectures and Panel Discussions

October 2: Deep sea corals: who, where and why we should care
Dr. Martin Willison, Biology, Dalhousie University and
Mr. Mark Butler, Ecology Action Centre.

November 6: Global Climate Change
Moderator: **Mr. Meinhard Doelle**, Director, Clean Nova Scotia.
Panelists: **Dr. Petr Chylek**, Atmospheric Science, Dalhousie University
Dr. Peter Duinker, Resource and Environmental Studies, Dalhousie University
Mr. George Foote, Energy Utilization, Nova Scotia Department of Natural Resources.

December 4: The Probability and Effects of an Asteroid Impact with Earth
Dr. David Turner, Astronomy & Physics, Saint Mary's University.

January 8: Simon Newcomb -The Maritimes' Greatest Scientist
Dr. Donald Betts, Physics, Dalhousie University

February 5: Mind Contemplating Mind - An Illustrated History
Dr. Raymond M. Klem, Killam Professor of Science in Psychology, Dalhousie University

February 19: The Motion of Curling Rocks
Dr. Mark R.A. Shegelski, Physics, University of Northern British Columbia

March 5: The Chemistry of Halifax Harbour - History and Future
Moderator: **Dr. Martin Willison**, Biology, Dalhousie University
Panelists: **Dr. Peter Strain**, Chemistry Section, Marine Environmental Division, Bedford Institute of Oceanography
Dr. Stephen Armstrong, Biology (Adjunct), Dalhousie University
Dr. Dale Buckley, Geological Survey of Canada, Bedford Institute of Oceanography
Dr. Tony Blouin, Manager of Environmental Policy, Planning & Development Services, Halifax Regional Municipality

April 2: Forensic Entomology: Flies that tell a tale
Dr. D.H. Strongman, Biology, Saint Mary's University

May 7: Structural Giants Have Feet of Clay?
Dr. T. Stanley Cameron, Chemistry, Dalhousie University
Annual Dinner Speaker

Librarian's Report

The number of NSIS exchange partners has remained almost constant and is currently 193. Six institutions cancelled their exchanges this year:

1. University of Georgia Libraries
2. Geological Survey of Canada
3. Netherlands Institute of Applied Geoscience TNO
4. Royal Society of New Zealand
5. Societe Nationale Elf-Aquitaine
6. Universite Pierre et Marie Curie

Institutional members now number 30, with one cancellation this year. Invoices were sent out in February 2001 for institutional memberships advising of an increase in membership fees to $20.00 (as per a motion passed at the NSIS AGM on May 3, 1999).

Volume 41, Part 4, 2001 of the *Proceedings* was mailed to institutional members and exchange partners in February 2001.

Six copies of *The Flora of Nova Scotia* by A.E. Roland were sold to students in a Dalhousie Biology class @$15.00 each.

The past year has been uneventful from the Library's perspective and operations continue to run smoothly.

Respectfully submitted,
7 May 2001
Sharon Longard
NSIS Librarian

Treasurer's Report
Income/Expense Statement
April 1, 2000 – March 31, 2001

OPERATING ACCOUNT			
Income			
Membership Fees	1,285.00		
Interest	2,628.65*		
Dinner	886.00		
Donations	20.00		
Total Operating Revenue		4,819.65	
Expenses			
Mailing	154.87		
Bank Charges	0.00		
Dinner	1,036.31		
Lecture Expenses	55.37		
Office Expenses	23.32		
Science Fairs	900.00		
Other	68.18		
Total Operating Expenses		2,238.05	
			2,581.60
PUBLICATIONS ACCOUNT			
Income			
NS Museum Grant	1,000.00		
Reprint & Page Charges	362.50		
Sales	845.68		
Total Publications Revenue		2,208.18	
Expenses			
Printing	3,414.55		
Mailing	979.63		
Other	0.00		
Total Publications Expenses		4,394.18	
			(2,186.00)
EXCESS INCOME/EXPENSES			**395.60**

(* Investment interest through February only)

March 31, 2001

ASSETS:			
Bank Account	$5,509.61		
Petty Cash	0.00		
		5,509.61	
Investments		48,081.33	
			53,590.94
Accounts Receivable			1,569.57
			55,160.51
LIABILITIES AND NET WORTH:			
Accounts Payable			118.56
Deferred Revenue			0.00
Permanent Fund		6,206.41	
Surplus (as of April 1, 1999)		44,688.00	
Excess Income		4,147.54	
			55,051.95
			55,160.51
INVESTMENTS:			
CIBC Premium T-Bill (monthly interest)		24,081.33	
CIBC Mortgage due 2001/04/17 @ 4.85%		8,000.00	
CIBC Mortgage due 2002/04/17 @ 4.90%		8,000.00	
CIBC Mortgage due 2003/04/17 @ 4.95%		8,000.00	
			48,081.33
RECEIVABLES:			
Interest (estimated)		1,121.23	
GST Refundable		448.34	
			1,569.57
PAYABLES:			
Alan Taylor		63.92	
Carolyn Bird		54.64	
			118.56

Respectfully submitted
David Goble
Treasurer

SESSION 2001-2002

President's Address

In the past year the Nova Scotian Institute of Science, through the work of the NSIS Council, has been involved in several useful scientific activities:

- five public lectures and one additional lecture postponed for next year
- two public panel discussions
- advertising of these public events through newspapers and radio
- supporting high school science fairs
- publication of the *Proceedings*
- developing strategies to improve advertising of meetings
- developing strategies to improve student participation in NSIS
- maintaining its library

The details of the speakers, moderators, titles and dates are listed in the Appendix.

All five public lectures took place, as usual, in the Nova Scotia Museum of Natural History. The two panel discussions took place at Saint Mary's University. We thank both of these institutions. Attendance again remained high. There was lively participation from the audience in the panel discussions that lasted at least an hour and a half. Discussion periods following the lectures also drew many questions and often lasted more than an hour. People from the media attended some of these events.

The changes to the By-Laws that were discussed in the Annual General meeting last year were approved nearly unanimously by responding members in a mail ballot.

The NSIS Council has worked very hard and well throughout the past year. Besides the hour and a half Council meetings before each of the public lectures and panel discussions, two extraordinary Council meetings took place during the year. Members of the Council participated in small subcommittees focusing on particular areas of interest of the Council, such as the program for the coming year, advertising public events, and involvement of students.

The committee responsible for the NSIS 2002-2003 program of public lectures and panel discussions has a complete list of these events and for most of them the speaker(s), moderator and some panelists have been confirmed. This program will be sent to the members during the summer.

The officers responsible for better advertising of the NSIS public events are now in the production stages of a high quality poster.

The student involvement committee is trying to find better ways to involve students in the activities of the Institute. A number of options have been discussed, ranging from co-sponsoring meetings with other similar organizations to fostering an annual student conference to be entirely hosted by the Institute. At present, the committee leans towards establishing a competition of written articles by the students on scientific issues, the winners of which could be published in the Proceedings and on the website. This would provide students with public recognition and a publication record, both important to their scientific development. The discussion of the number of awards/prizes for both undergraduate and graduate students, details of the presentation event(s) etc. will continue and be completed in 2002-2003, if the Council finally deems this the best way to start better communication with students.

The NSIS Council is also involved through some of its members in the "Science -A Family Affair" program. We believe that parents have an important role in the education of their children and they are willing to play that role provided we make it possible for them to do so. The "Science - A Family Affair" program provides an opportunity for families to experience, question and investigate science through hands-on activities. The objectives of the program are:

> To encourage families to learn scientific ideas and processes from a wide variety of interesting topics.
>
> To focus on having fun with science.
>
> To foster communication between parents and children.

The "Science - A Family Affair" workshop usually takes place in May at Dalhousie University on a Saturday. Invitations are sent out to 5 or 6 schools in the Metro area and they are asked to select 5 families from each school who are willing to participate in the workshop. The program is open to grades 3, 4, 5, and 6 students.

The Nova Scotian Institute of Science also encourages the science fair movement by providing a cash award of $100 to the student with the best project in each of the seven regions across Nova Scotia.

The Bras D'Or Lakes issue of the *Proceedings of the Nova Scotian Institute of Science* is in the printer's hands and it is anticipated that it will be available for distribution sometime in June. The environmental issue, which will be a mixture of environmental papers and others, is next in line for completion and an issue on marine science is in the planning stage.

The overall membership of the Institute is about 120, however many of these have not yet paid their dues for this year. Both the membership officer and the treasurer have continued their efforts to recruit members.

The Institute communicates with most of its members by e-mail. The same material is sent by Canada Post to those members who do not use e-mail.

The Institute has had another successful year and it is well positioned to continue its activities in the future. I thank members for supporting the activities of the Institute and for their suggestions on how our activities can be improved in innovative ways.

6 May 2002
Georgia Pe-Piper
President

Appendix: Lectures and Panel Discussions

October 1: The Scientific Thinking of Sherlock Holmes
Dr Richard Brown, Psychology Department, Dalhousie University
November 5: Oil and Gas Offshore Nova Scotia
Moderator: **David Piper**, Geological Survey of Canada, Atlantic
Panelists: **Graham Williams**, and **Hans Wielens**, Geological Survey of Canada, Atlantic
Doug Gregory, Shell Canada Ltd
Brent Austin, PanCanadian Energy
M. Rafiqul Islam, Killam Professor of Petroleum Engineering, Dalhousie University
December 3: Show or Tell
Dr Philip Cox, Faculty of Computer Science, Dalhousie University
January 7: Reflections on Lichenology: Achievements over the Last Forty Years and Challenges for the Future
Dr David H.S. Richardson, Biology Department, Saint Mary's University (Dean of Science)
February 4: Testing the Waters -the condition of our lakes and rivers
Moderator: **Robert Chambers** (former Head of Biochemistry, Dalhousie University)
Panelists: **Joseph Kerekes**, Emeritus Research Scientist, Canadian Wildlife Service
Walton Watt, former Head Freshwater Fish Habitat Research, DFO
Wesley White, retired DFO biologist
Tony Blouin, Manager, Environmental Policy, HRM
April 1: Alien invasions off our coast
Dr Robert Scheibling
Cancelled because of the strike of the Dalhousie University Faculty Union; rescheduled for October 7th 2002.
May 6: Fishing for a cure for diabetes
Dr James R. Wright, Department of Pathology, Dalhousie University

Librarian's Report

The number of NSIS exchange partners has remained almost constant and is currently 192. One institution cancelled their exchange this year:

1. University of Illinois Library

Institutional members now number 29, with one cancellation this year. Invoices were sent out in March 2002 for institutional memberships.

No *Proceedings* were published during the year so there was no mailing to members and exchange partners.

Five copies of *The Flora of Nova Scotia* by A.E. Roland were sold to students in a Dalhousie Biology class @ $15.00 each.

The Special Projects librarian in the Killam Library at Dalhousie University, Alison McNair, is assisting me with the ongoing project of adding titles of journals that have ceased publication or are no longer being received on exchange to the Novanet catalogue so users will know of their availability. This is an extensive project which she works on as her time permits. Dr. Jonathan Blay and Ms. McNair have updated the NSIS webpages to reflect the periodical titles in the NSIS Library.

The Library continues to run smoothly.

Respectfully submitted,
May 6, 2002
Sharon Longard
NSIS Librarian

Editor's Report

1) CanCopy -The Council accepted the Editorial Board's recommendation to join as an affiliate of the Canadian Copyright Licensing Agency, CanCopy. All of the requisite information was supplied and the signed copies of the agreement were filed with both CanCopy and the NSIS Secretary on November 3, 2001.

2) The 'Oceanography of the Bras d'Or Lakes' issue of the *Proceedings* (B. Petrie - guest editor) is now virtually complete. A minimum amount of tidying up required on the last paper will be complete this week and the issue then will be placed in the hands of the Production Editor. It is hoped that it will be ready for distribution by the end of June.

3) The NSIS *Proceedings* issue on Conservation in Nova Scotia (M. Willison - guest editor) has not progressed further because of Dr. Willison's heavy involvement in teaching and other duties. Now that the academic term is complete it may be possible to prepare this issue for publication as a conservation issue or, failing that, as an issue that contains some conservation papers with the balance made up of other general papers. The intent is to have this issue published during this calendar year.

4) Special Issue on the First International Symposium on Deep Sea Corals (M. Willison- editor) was originally slated for co-publication with the Ecology Action Centre. In the event it was agreed that it would be simpler for it to be published by the Ecology Action Centre alone. This was done and the volume appeared this spring.

5) Marine Science Issue. Plans for an issue focusing on a comprehensive discussion of the fundamentals and objectives of physical and biological oceanography, marine ecology and geology and their applications were announced last year. Further work on this has taken place.

6) No Board meetings were held this past year; the next Board meetings will be held in the fall when it is expected that there will be more issues to discuss.

Respectfully submitted
May 6, 2002
James E Stewart
Editor

Treasurer's Report
Income/Expense Statement
April 1, 2001 – March 31, 2002

OPERATING ACCOUNT			
Income			
Membership Fees	817.50		
Interest	1,633.98		
Dinner	961.00		
Donations	500.00		
Total Operating Revenue		3,912.48	
Expenses			
Bank Charges	0.00		
Dinner	1,028.50		
Lecture Expenses	54.64		
Science Fairs	500.00		
NS Museum Rental	60.00		
Chebucto Free Net	50.00		
Other	129.37		
Total Operating Expenses		1,822.51	
			2,089.97
PUBLICATIONS ACCOUNT			
Income			
Reprint & Page Charges	275.00		
Inst Memberships & Sales	1,015.60		
Total Publications Revenue		1,290.60	
Expenses			
Mailing	146.88		
Total Publications Expenses		146.88	
			1,143.72
EXCESS INCOME/(EXPENSES)			**3,233.69**

April 1, 2002

ASSETS:

Bank Account	$6,919.89		
Petty Cash	0.00		
		6,919.89	
Investments		49,835.52	
			56,755.41
Accounts Receivable			448.34
			57,203.75

LIABILITIES AND NET WORTH:

Accounts Payable		606.28	
Deferred Revenue		0.00	
Permanent Fund	6,206.41		
Surplus (as of April 1, 1999)	48,393.32		
Excess Income	1,997.74		
			56,597.47
			57,203.75

INVESTMENTS:

CIBC Premium T-Bill (monthly interest)	13,823.15	
CIBC Cash	12.37	
CIBC Mortgage due 2002/04/17 @ 4.90%	8,000.00	
CIBC Mortgage due 2003/04/17 @ 4.95%	8,000.00	
Maple Trust GIC due 2004/05/09 @ 5.20%	10,000.00	
National Trust GIC due 2005/05/09 @ 5.20%	10,000.00	
		48,081.33

RECEIVABLES:

GST Refundable	448.34	
		448.34

PAYABLES:

Science Fairs	500.00	
Science Workshop	106.28	
		606.28

Respectfully submitted
David Goble
Treasurer

SESSION 2002-2003

President's Address

The past year has been quite eventful, with a number of initiatives intended to raise the profile of NSIS and to increase the involvement of students in our activities. Firstly, we produced a high-quality poster that introduced the Institute and outlined the year's program in advance. This was distributed to over 60 university departments throughout the province, sent to local high schools, and posted in other public places throughout Metro, including many local libraries. We also updated our introductory brochure and membership application form. This was also widely distributed, and has brought in some new members. As usual, we have supported a number of regional science fairs, and have lent our support to a bid to bring the Canada-wide Science Fair to Nova Scotia in 2007.

A considerable effort was put into launching our first Science Awards Competition for students at a university level. This competition is open to anyone registered at an educational institution within Nova Scotia, and prizes are offered not only to science students, for either experimental papers or reviews, but also to a student in a nonscientific discipline who shows the talent for transcribing scientific information into a form appreciated by the general public. This year the Institute was pleased to award three prizes, two in the graduate category and one in scientific writing. Submissions were received from both within and outside of Metro. The prizes extended across three different institutions (Dalhousie University, Saint Mary's University and the University of King's College) and addressed all levels of study (undergraduate, MSc and PhD). We were pleased to award the prizes to the recipients in person at our April meeting, and look forward to seeing the submitted articles in a future issue of the *Proceedings of the Nova Scotian Institute of Science.*

An issue of the *Proceedings* (on the Bras d'Or Lakes) was published in 2002, and the *Proceedings* continues to progress under the able direction of its Editor, Dr James Stewart.

There have been a number of changes in the membership of Council over the past year and at its end. I express my gratitude and appreciation to all members of Council, who have worked hard, but certain individuals need special mention for their extensive contributions and particular efforts over the past year. This year sees the departure from Council- at least for the time being -of Sherry Niven and Stephen Payne, both of whom have contributed greatly to the Institute for many years. We thank them sincerely. The year also saw the departure in March, to another province, of our Treasurer, David Goble; and we are very grateful to Stephen Ewart, who took over the work of Treasurer in mid-stream and at a time when there were many tasks needing care. Sterling work has also been done by Truman Layton, our Secretary, who took over the job last year with little preparation but who has done marvellously well. I thank particularly our student representatives for this year, Andrew Hamilton and Colleen Nordlund, who have managed to find time from their studies to provide us with invaluable help and advice. Finally, thanks must surely go to this year's Vice President, Archie McCulloch, who has worked hard in many contexts including the organisation of this annual meeting and helping to open up links with the Discovery Centre, which we hope will lead to a valuable relationship in the future. We look forward to Archie's leadership in the coming year.

Respectfully submitted
5 May, 2003
Jonathan Blay
President

Appendix: Lectures and Panel Discussions

October 7:	Alien Invasions Off Our Coast. Aliens have invaded our coast! Are we prepared for an ecosystem phase shift? **Robert Sheibling**, Biology, Dalhousie University
November 4:	Science Needs for the Sustainable Management of Terrestrial Natural Resources in Nova Scotia? Moderator: **Bill Freedman**, Biology, Dalhousie University
December 2:	Vertebrate Biology in Microgravity (Do we really need the international space station? **Richard Wassersug**, Anatomy & Neurobiology, Dalhousie University
January 6:	Why Do We Need a Dirty Atmosphere? Aerosol effects on clouds, climate and the hydrological cycle. **Ulrike Lohmann**, Physics & Atmospheric Science, Dalhousie University
February 3:	Introduction of Exotic Species and Biological Methods in Pest Management. Moderator: **Mark Butler**, Ecology Action Centre
March 3:	Tides and Storm Surges in the Bay of Fundy, and a Case Study of Flooding Potential. **Charlie O'Reilly**, Canadian Hydrographic Service (DFO) **Allan Ruffman**, Geomarine Associates Ltd **George Parks**, Canadian Hurricane Centre, Environment Canada
April 7:	Molds in Our Midst – Sick Buildings and *Stachybotrys* **Tom Rand**, Biology, Saint Mary's University
May 5:	Was it Hippocrates, Descartes or George Bush Who Said…? The use and abuse of quotations in lectures. **Jock Murray**, Faculty of Medicine, Dalhousie University Annual Dinner Speaker

Librarian's Report

There are currently 192 NSIS exchange partners and this number remains unchanged from last year. Institutional members number 27, with two cancellations this year. Invoices were sent out in February 2003 for institutional memberships, and 17 have renewed thus far.

The latest issue of the *Proceedings of the Nova Scotian Institute of Science* v.42, pt. 1, 2002 was mailed to all exchange partners and institutional members in March 2003. The cost for this mailing was $1202.25. In addition, this year, the Librarian agreed to mail out the new issue of the Proceedings to all personal members, along with the AGM announcement, dinner registration form and membership renewal form. The cost for this mailing was $200.86

The Flora of Nova Scotia by A.E. Roland continues to sell and this year 14 copies were sold @ $15.00.

Publications continue to be received regularly from our 192 active exchange partners and this material is added on an ongoing basis to the collection.

I would like to thank Carol Richardson and the Serials Department at the Killam Library who ensure that the NSIS Library operations continue to function smoothly.

Respectfully submitted

April 22, 2003
Sharon Longard
NSIS Librarian

NSIS 2003 ANNUAL GENERAL MEETING
Editor's Report

1) An Editorial Board meeting was held October 3, 2002 to prepare recommendations to deal with questions posed by the Executive Council. In response it was recommended to Council that:

   a) The price for the sales of copies of the *Proceedings* should be set at total production and distribution costs per copy plus 15% to compensate for unforeseen and unexpected publication costs.

   b) i) Council should not at this time engage in electronic publishing of the *Proceedings* for several reasons including the requirement to provide hard copies for the Exchange list, libraries and some subscription members plus the fact that none of the current Editorial Board is sufficiently expert to handle the problems associated with electronic publishing.

   ii) As an alternative, consideration should be given to collecting and preparing for posting to the website, Abstracts and Tables of Content of issues of the previous decade.

   Action: Council accepted recommendations (a) and (b i) and requested that further consideration should be given as to how (b ii) could be arranged.

2) Six hundred copies of Volume 42 Part 1 of the *Proceedings of the Nova Scotian Institute of Science* [The Oceanography of the Bras d'Or Lakes: B. Petrie, Guest Editor] were printed and distributed to the Exchange list, institutional subscriptions and the membership list. All extra copies of the issue (approximately 220) have been sold and currently we are attempting to gauge the additional demands so as to order a second printing.

3) The next issue of the *Proceedings* [on Environment and Diversity: M. Willison, Guest Editor] is almost ready for production work and should be ready for distribution by the beginning of the 2003-2004 NSIS season.

4) Sufficient materials are in hand and/or nearing completion for a subsequent issue which we anticipate will appear in the late fall or early in 2004.

Respectfully submitted
May 5, 2003
James E. Stewart
Editor NSIS

Treasurer's Report
April 30, 2003

ASSETS:			
Bank Account	$11,672.96		
Petty Cash	0.00		
		11,672.96	
Investments		47,260.40	
			58,933.36
LIABILITIES AND NET WORTH:			
Accounts Payable			0.00
Total Liabilities and Net Worth			**$58,933.36**

INVESTMENTS:		
CIBC Premium T-Bill (monthly interest)	8,864.40	
GIC due 04/22/08 @ 4.40%	8,396.00	
GIC due 06/02/07 @ 3.60%	10,000.00	
Maple Trust GIC due 2004/05/09 @ 5.20%	10,000.00	
National Trust GIC due 2005/05/09 @ 5.20%	10,000.00	
		$47,260.40
RECEIVABLES:		
Proceedings Invoices outstanding	3,025.00	
GST Refundable	448.34	
		$3,473.34
Notes		
Printing cost of Proceedings	13,352.40	
Dal Graphics	1,015.00	
Mailout	1,202.25	
		$15,569.65
Revenue to date:	12,146.25	

Membership stands at 137

Respectfully submitted
April 30, 2003
Stephen Ewart
Treasurer

Instructions to Authors

The *Proceedings of the Nova Scotian Institute of Science* publishes papers in English or French. Manuscripts must be typewritten double-spaced with 4 cm margins. Disk copies in Word or WordPerfect are preferred, but must also be accompanied by three paper copies of the manuscript. A summary of no more than 200 words, free of formulae, must be included at the beginning of the paper, followed by key words or phrases. This should be followed by an introduction, methods, results or observations, discussion and references. In some cases a combination of these sections may be more effective. Underline only material to be set in italics, and use capital letters only when the letters or words should appear in capitals in the printed paper. Layout and style should follow that used in recent volumes. Each page of the manuscript should be numbered, the first page carrying only the title, authors' names and affiliations and any necessary footnotes. Spelling should follow that of Webster's Third New International Dictionary. Abbreviations, nomenclature, and symbols for units of measurements should follow international recommendations. SI units should be used whenever possible. Use day-month-year sequence for dates. Do not use periods after abbreviations. Photographs should be mounted on Bristol board ready for reproduction. Prints must be of high quality on glossy paper with no space between those mounted in groups. Color illustrations will be accepted at the discretion of the Editor. The cost of color reproduction is borne fully by the authors who must submit a statement accepting this responsibility. References are to be collected at the end of the paper and referred to in the text by inclusion of the author's name and year of publication. The list of references should be consistent with the following examples:

Periodicals	Nielsen KJ, Franz DR (1995) The influence of adult conspecific and shore level on recruitment of the ribbed mussel *Geukensia demissa* (Dillwyn). J Exp Mar Biol Ecol 188:89-98
Books	Cushing D, Walsh J (1976) The ecology of the seas. WB Saunders Company, Toronto
Papers from books or symposium proceedings	Lee GF (1975) Role of hydrous metal oxides in the transport of heavy metals in the environment. In: Krenkel PA (ed) Heavy metals in the aquatic environment. Pergamon, Oxford, p 137-147
Pers. comm.	Smith AJ (2001) (Nova Scotia Department of Agriculture, Halifax) Personal communication

Tables should be numbered consecutively in bold-faced Arabic numerals and must have brief titles that are self-explanatory; each table must be typed on a separate page.

Illustrations are to be numbered consecutively in Arabic numerals. Captions should be self-explanatory and typed on a separate page. Two paper copies of each are required even when they are embedded in an electronic file. All lines in drawings must be of suitable thickness to reproduce well when published in the *Proceedings*. Similarly, letters and symbols in drawings should be at least 2 mm high when reduced to the size used in the *Proceedings*.

Page Charges. Currently a charge of $25 per page is levied to help defray the cost of publication. This amount is charged to the institution or a contract supporting the research reported in the published paper. In no case will acceptance of the paper be dependent upon payment of the page charges.

Authors are responsible for editing the galley proofs. Orders for reprints, in addition to the 15 supplied gratis to the corresponding author, must be received when the galley proof is returned.

Papers should be sent to the Editor:

JE Stewart, Department of Fisheries & Oceans
Bedford Institute of Oceanography, PO Box 1006
Dartmouth, NS, Canada B2Y 4A2
E-mail: stewartje@mar.dfo-mpo.gc.ca

LUESTER T. MERTZ
LIBRARY

JUL 08 2004

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BOTANICAL GARDEN

New York Botanical Garden Library
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